Reconnaissance Watershed and Hydrologic Analysis on the

Upper Agua Fria Watershed

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in cooperation with the
Upper Agua Fria Watershed Partnership

funded by
Arizona Rural Watershed Initiative

and administered by
Arizona Department of Water Resources

cartographic composition by
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University of Arizona

ACKNOWLEDGEMENTS

This project was made possible by the efforts of the Upper Agua Fria Watershed Partnership and all of its members. The coordination and leadership from Chairperson Mary Hoadley is greatly appreciated. Encouragement and information relevant to the project were provided by a number of members. Among these were Bonnie Glasgow who provided some historical references, Phil Albins with information regarding Black Canyon City, and Kip Herstead who used ongoing results from the analysis in developing educational materials for the community.

The Arizona Department of Water Resources was instrumental in guiding formation of the group and providing advice on obtaining funding. Dennis Sundie provided the initial guidance which was continued by John Fortune.

Although the Upper Agua Fria Watershed Partnership has been conspicuous by the predominance of local citizenry, as compared to agency professionals, those individuals representing government agencies were very helpful. Max Enterline of ADEQ provided technical references and shared information specific to this project, in addition to his regular participation in the partnership. John Munderloh, Yavapai County Water Coordinator, provided information through Yavapai County's GIS database in the areas of water uses, as well as being a valuable general reference and reviewer.

Representatives of the Bureau of Land Management made information available and took the time to explain its context. Kathy Pedrick, Chris Horyza, Tim Hughes, and Lin Fehlman were all helpful. Prescott National Forest information and interpretation was provided by Doug MacPhee, Michele Girard, and Ruth Valencia. Rich Martin and staff from the Tonto National Forest likewise provided information. Obtaining information from the Bureau of Reclamation was facilitated by Mary Reese.

Gavin Fielding from the Hydrology and Water Resources Department of the University of Arizona helped identify references in the field of geology and obtained infrared satellite imagery of the watershed and surrounding areas which has been very useful. Ruiyun Jiang of the School or Renewable Natural Resources provided skilled services in converting graphics into printable and readable documents.

Ed McGavock provided valuable review and discussion, as well as sharing information on base flow of the Agua River at Humboldt.

Finally, the numerous maps and data derived from GIS databases were the result of work by Patrick Barabé of the Advanced Resource Technology Group in the School of Renewable Natural Resources.

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In partial fulfillment of the deliverable requirements of Agreement No. 24386 between the Arizona Department of Water Resources and the University of Arizona, School of Renewable Natural Resources.

BACKGROUND

Over the last several years residents within the Agua Fria Watershed have become increasingly aware of the need to learn about, and plan for management of, the water resources on which they depend. Beginning with a workshop sponsored by the Big Bug Economic Development Council and supported by Arizona Public Service, a citizens group developed and formed a local watershed group – the Upper Agua Fria Watershed Partnership. In October 2000 a stakeholders' workshop was held to identify major issues which needed to be addressed.

Yavapai County is one of the most rapidly growing areas in Arizona. The adjacent Prescott Active Management Area (Prescott AMA) was declared in a state of groundwater mining in early 1999, meaning that new major water users have to obtain water sources other than new use of groundwater. This is expected to divert new major developments to adjacent areas not governed by AMA rules. The area's mild climate, existence of transportation and utility corridors, and proximity to the rapidly growing Phoenix metropolitan area all contribute to the expected growth. There are existing private lands as well as Arizona State Trust lands which could be developed following sale or long term lease. There are concerns that new major uses of groundwater might impact existing water users. There are also needs to know where the water resources can best be developed to accommodate increased growth with minimal impact to existing uses, including instream flows.

Maintaining and improving watershed health was identified by stakeholders as very important. This included both the upland areas of the watershed and the riparian or stream course areas.

WATERSHED DESCRIPTION AND CHARACTERIZATION

A. Geography

The Upper Agua Fria watershed has been delineated by the Arizona Department of Water Resources. It is the area which drains to the dam of Lake Pleasant, exclusive of the portion of the watershed included in the Prescott AMA. However, analysis of Lake Pleasant, itself, and its water quality are outside the scope of this report.

The watershed is located in central Arizona and comprises approximately 1,265 square miles. This does not include the approximately 175 square miles of the Agua Fria watershed located within the Prescott AMA but separated somewhat by a groundwater barrier which causes groundwater to leave the AMA as base flow in the Agua Fria River. Throughout the report it may be referred to as "the watershed". Figure 1 illustrates the general geography of the watershed.

The Agua Fria River flows generally from north to south for a distance of approximately 67 miles and an elevation ranging from approximately 4400 feet at the Humboldt gage to less than 1600 feet where it enters Lake Pleasant. The watershed ranges from an elevation of 7,979 feet on Mt. Union to less than 1600 feet at Lake Pleasant. It is approximately 50 miles long from Mingus Mountain on the north to Lake Pleasant Dam on the south, and 30 miles wide from the Verde Rim on the east to the crest of the Bradshaws on the west.

Almost all of the watershed is within Yavapai County. According to the Geographic Information System (GIS) database about 39,915 acres or 5 percent of the watershed is in Maricopa County. This portion includes the southeast corner and southernmost edge, including New Waddell Dam which impounds Lake Pleasant. There are no incorporated communities within the watershed. Unincorporated communities include Mayer, Spring Valley, Cordes Lakes, Black Canyon City, Crown King and Arcosanti. There is some scattered residential development where former ranch headquarters or mining claims have been split into subdivisions or smaller parcels to accommodate this use. Areas with some residential development include Bumble Bee, Cleator, Pine Springs, Big Bug Creek, Poland Junction, Bensch Ranch Estates, and Dugas. The Orme Ranch and School includes both a boarding school and irrigated farm land.

Table 1 and Figure 2 illustrate landownership and management:

ENTITY	ACRES	Percent
Arizona State Trust	94,420	11.7
Bureau of Land Management	241,810	29.9
Bureau of Reclamation	17,810	2.2
National Forest	377,940	46.7
Private	76,250	9.4
Maricopa County	1,505	0.2
City	5	0
TOTAL	809,740	100

The terrain varies widely from gentle plains to rugged mountains and steep, narrow canyons and is closely reflective of the geologic structure. The Bradshaw Mountains on the west contain some of the steeper terrain, with ridgetops and benches intervening among steep slopes and canyons. The eastern side contains a number of gently sloping mesas, including Perry Mesa and Black Mesa, and rises gently to the northeast, punctuated in the northern portion by some relatively small volcanic cones. The area in the southwest portion – west and northwest of Lake Pleasant – is relatively densely

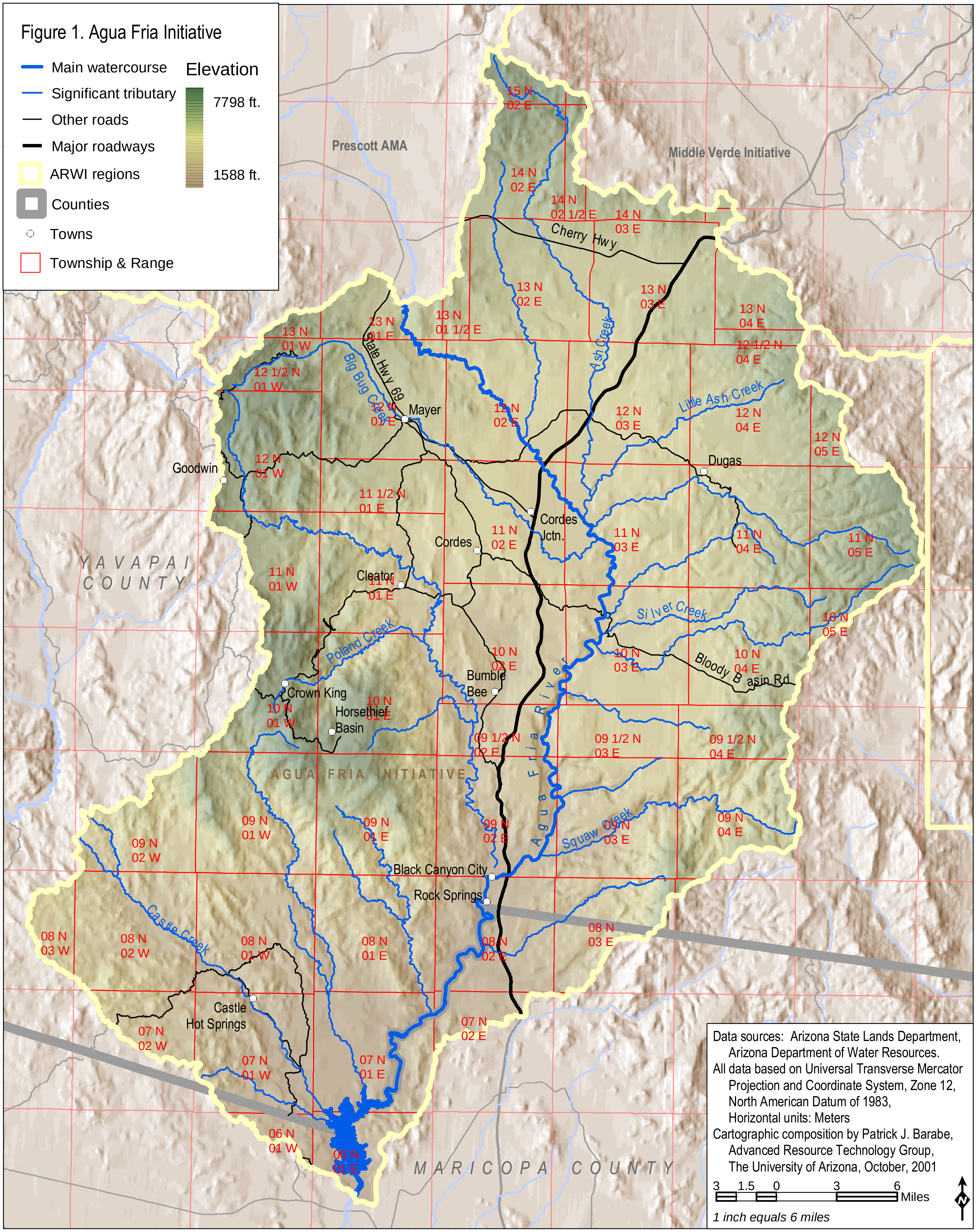

Figure 1. Agua Fria Initiative
Main watercourse
Significant tributary
Other roads
Major roadways
ARWI regions
Counties
Towns
Township & Range
Elevation
7798 ft.
1588 ft.
Prescott AMA
Middle Verde Initiative
YAVAPAI COUNTY
MARICOPA COUNTY
AGUA FRIA INITIATIVE
Agua Fria River
Cherry Hwy
State Hwy 69
Bloody Basin Rd
Big Bug Creek
Ash Creek
Little Ash Creek
Silver Creek
Poland Creek
Squaw Creek
Castle Creek
Mayer
Goodwin
Dugas
Cordes Jctn.
Cordes
Cleator
Crown King
Horsethief Basin
Bumble Bee
Black Canyon City
Rock Springs
Castle Hot Springs
Data sources: Arizona State Lands Department, Arizona Department of Water Resources.
All data based on Universal Transverse Mercator Projection and Coordinate System, Zone 12, North American Datum of 1983, Horizontal units: Meters
Cartographic composition by Patrick J. Barabe, Advanced Resource Technology Group, The University of Arizona, October, 2001
3 1.5 0 3 6 Miles
1 inch equals 6 miles
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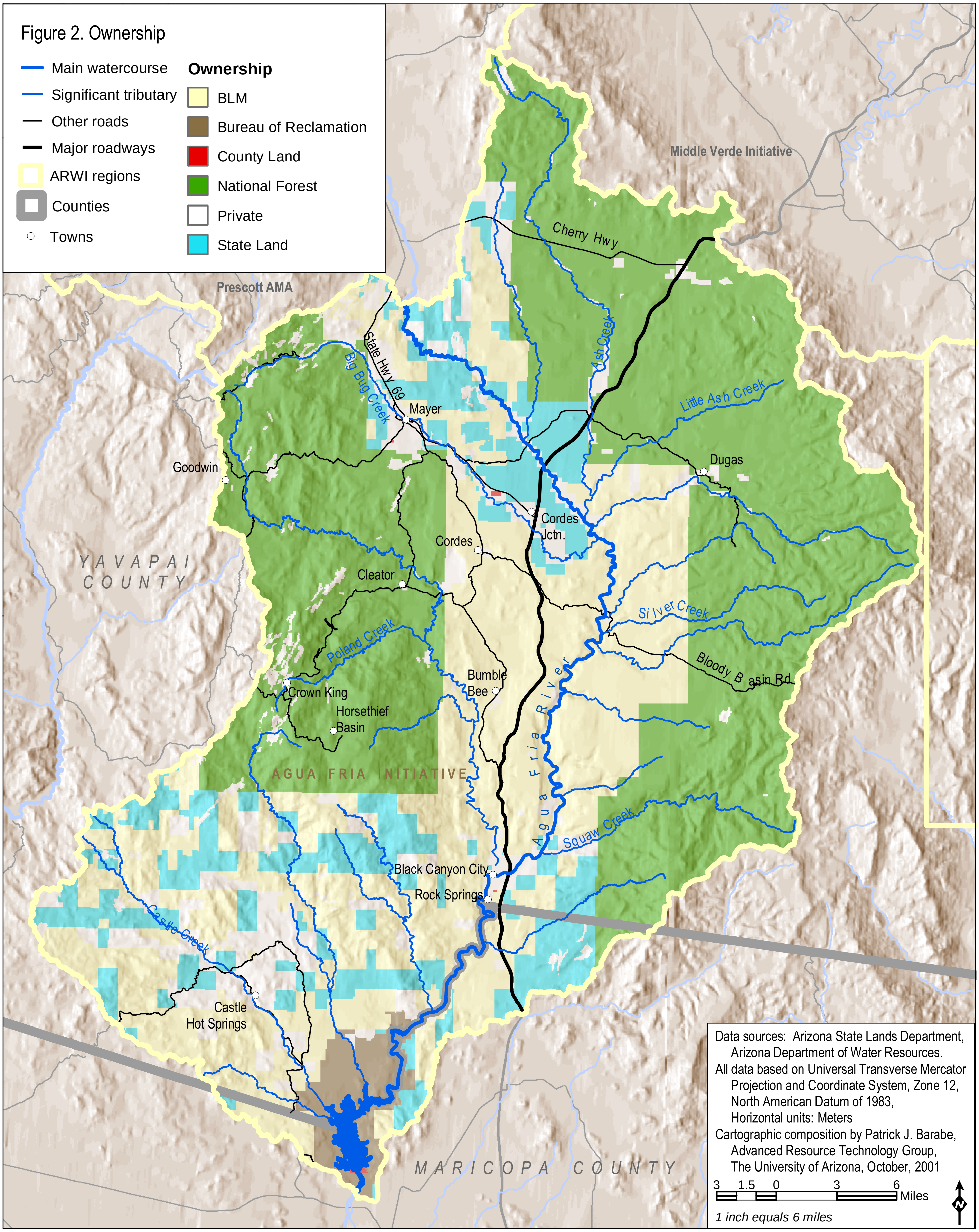


Figure 2. Ownership

dissected with ridges and drainages. Areas in the northwest portion are gently rolling with drainages roughly parallel.

B. Climate

The climate ranges from hot and relatively dry in the lower desert elevations at the southern end to temperate and more moist at the upper elevations on Mingus Mountain, Bradshaw Mountains and Pine Mountain area. Two primary periods of precipitation occur – the summer "monsoon" of July into September characterized by often intense thunderstorms, and the winter period of frontal storms which has most of its amount in December through March. More detailed information on climatic processes can be found in a number of references including Sellers and Hill (1974).

The annual precipitation map shown in Figure 3 illustrates the isohyetal (equal precipitation) lines of the watershed for the 30 year period, 1961-1990. Mean annual precipitation varies from about 12 inches in the Lake Pleasant vicinity to nearly 30 inches along the Bradshaw Mountain crest near Crown King. The relationship of precipitation to elevation is evident.

There are several weather stations within and near the watershed. The following are precipitation gages with longer periods of record.

TABLE 2. AGUA FRIA WATERSHED PRECIPITATION GAGES

GAGE	Elevation ft.	Period of Record water years	Missing or incomplete
Bumble Bee	2500	1954-79	1979 incomplete
Castle Hot Springs	1990	1932-35, 1961-present	1996,97,99,2000 incomplete
Castle Hot Springs 4N	2800	1907-14,1950-58	1914,58 incomplete
Cordes	3770	1927-present	2000 incomplete
Crown King	6000-5920	1916-94 95-present Forest Service	1919,23,24,25,27,31,48,50,52,89 incomplete
Dugas 2SE*	4000-4040	1920-1972	1922,23,24,46,49,59 incomplete
Lake Pleasant	1540	1950-77	1950,75,76 incomplete
Prescott**	5520-5210	1870-present	1873,1875,1907,45,98 incomplete

Records through April 1998 from University of Arizona Department of Atmospheric Physics weather records http://ag2.calsnet.arizona.edu/cgi-bin/weather.cgi,
For the period May 1998-Sept 2000 from Arizona Climate Summaries,
http://www.wrcc.dri.edu/summary/climsmaz.html Records are rearranged to display by water year (October – September) rather than calendar year. First year shown in period of record is first year with complete, or almost complete, water year, and last year is last year with complete, or nearly complete, water year. Years shown as incomplete have one or more months with enough days missing that no record is shown in the Arizona climate records. Elevations shown as differing are due to changes in station location with elevations in sequence of station location.

* Previously designated as Sycamore Ranger Station.

** Although not located within the Agua Fria Watershed, Prescott is close by and represents the longest term precipitation record available near the watershed. The Arizona Climate Summaries give precipitation data from 1898 forward. The University of Arizona weather records extend back into the late 1860's.

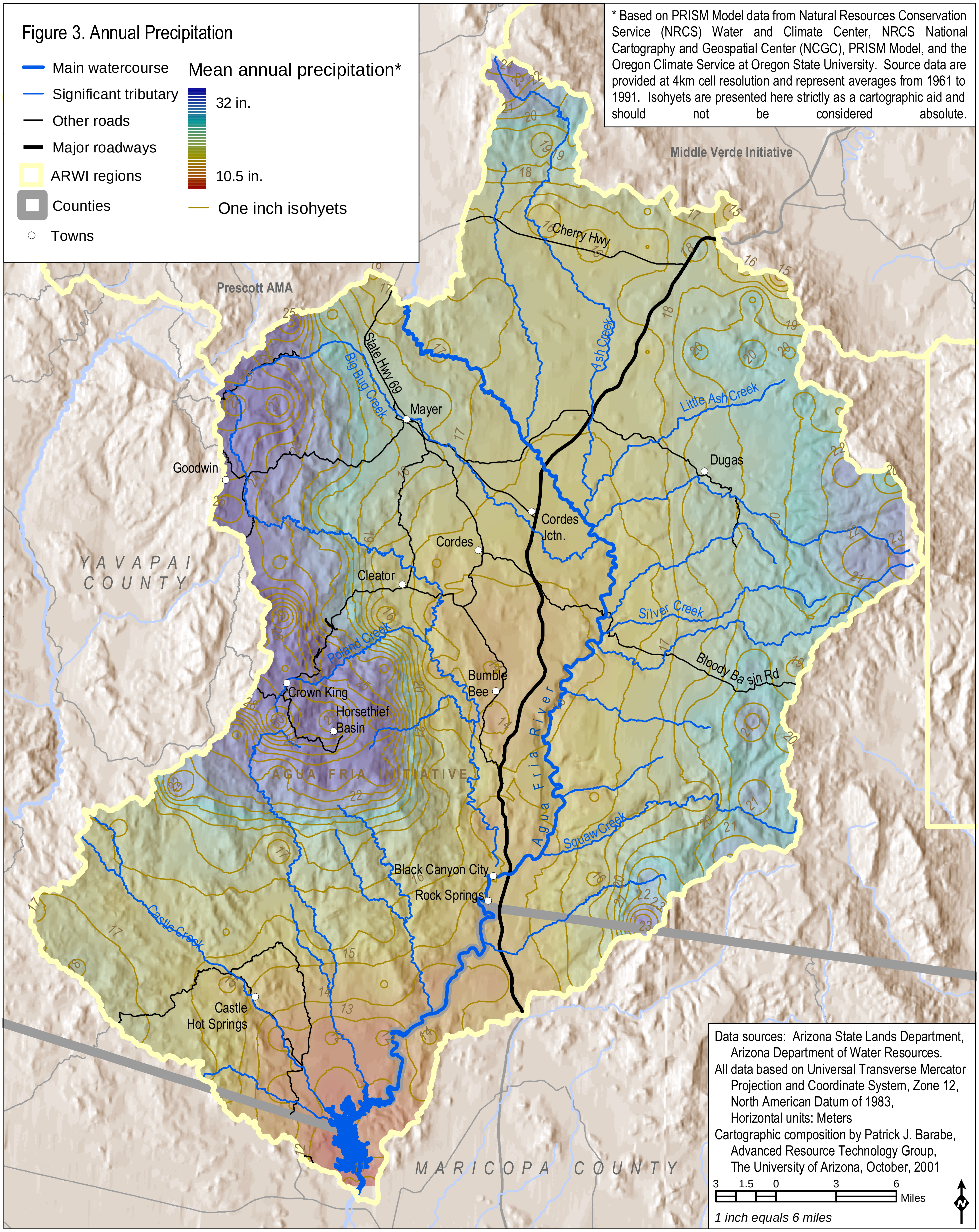


Figure 3. Annual Precipitation

The following table illustrates locations of additional weather stations listed in the directory of the National Climatic Data Center. Some have data available by purchase.

Station	Elevation	Period of record (water years)
Black Canyon City	2070	1976-present
Mayer 3NW	4640	1949-1983
Mayer	4500	1984-86
Mayer #2	4340	1987-present
Mingus Mtn.Lookout	7660	1949-76
Mount Union	7970	1949-65
Mount Union #2	7710	1963-76

Figure 4 displays the long term precipitation at Prescott from 1876 to 2000. (Months missing from the Prescott record were estimated using monthly regression correlations with stations at Jerome or Cordes for periods when neither station was moved. They are used to help display the time trend.) The figure displays precipitation for the water year as a whole and also divided into winter (October-April) and summer (May-September) components. Historic analysis in northern Arizona has found that the majority of runoff reaching downstream reservoirs is a result of winter precipitation.

The National Weather Service calculates 30 year "normal", or mean, temperatures and precipitation every ten years. A "departure from normal" is the difference from the average for the 30 years ending in the last census year. Although the 1971-2000 means have recently been published, the previous ones are used here for consistency with maps. The following illustrates the relationship between means calculated for the last 125 years, 100 years, and the most recent two 30 year normal periods for Prescott.

Period	Mean Annual Temperature	Mean Annual Precipitation
1876-2000	NA	18.66 inches
1898-2000	53.2° F.	19.32 "
1961-1990	53.0 "	19.63 "
1971-2000	53.7 "	19.19 "

As shown, the 1961-1990 period is slightly above the long term average precipitation and slightly below the long term average temperature. By contrast, the most recent 30 year period – 1971-2000 -- is slightly below the long term in precipitation and above in temperature.

Figure 5 illustrates the variation over time of a calculated 30 year "normal" precipitation for Prescott with the records extending back to 1876 using a moving mean, i.e., each year's entry is the mean of the 30 year period ending with that year. For example, the first year, 1905, is the mean for 1876 through 1905. As it displays, the "normal" precipitation varies considerably depending on the time period. Although the long term mean is 18.66 inches the 30 year mean varies from a low of 15.83 inches for the first 30

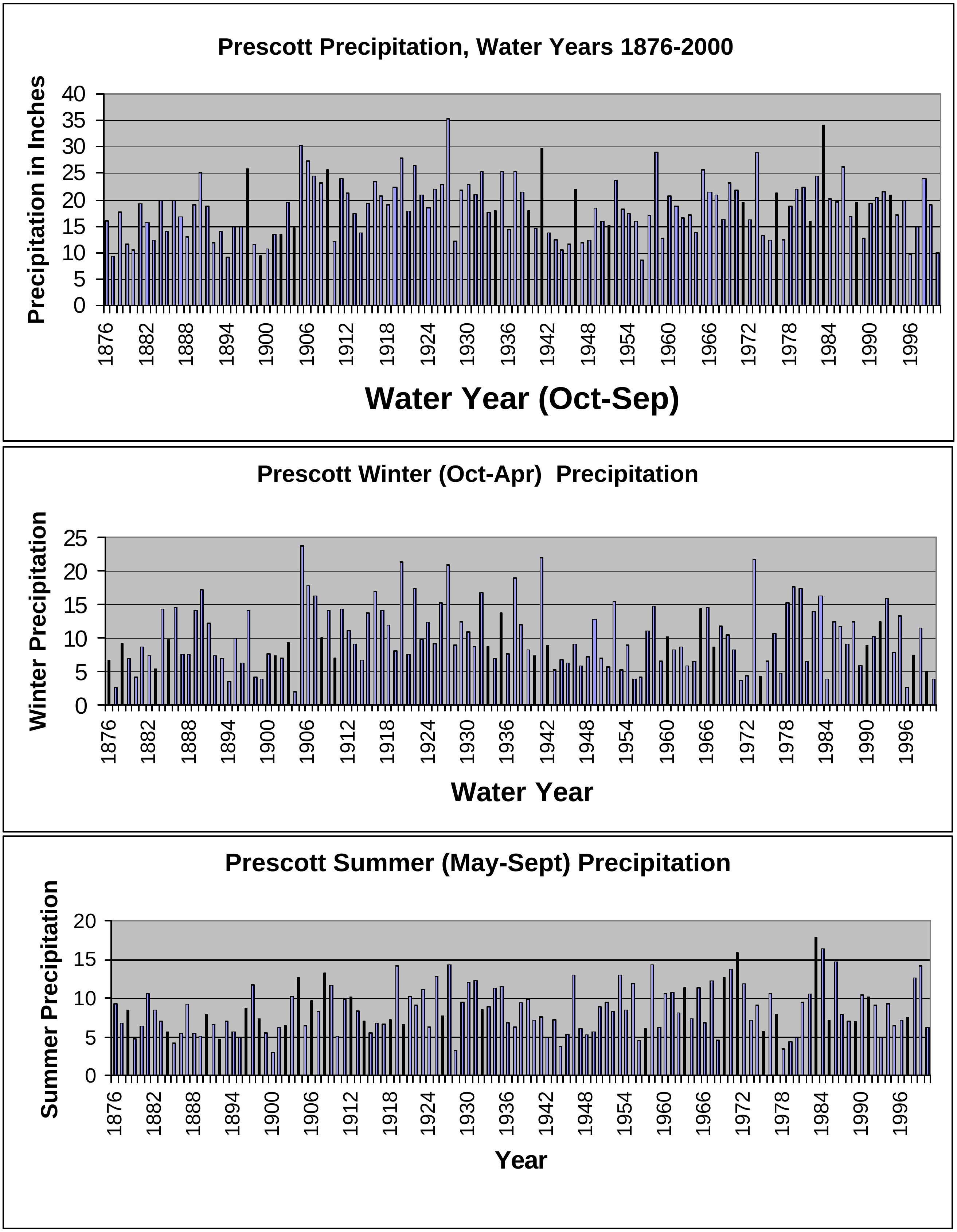
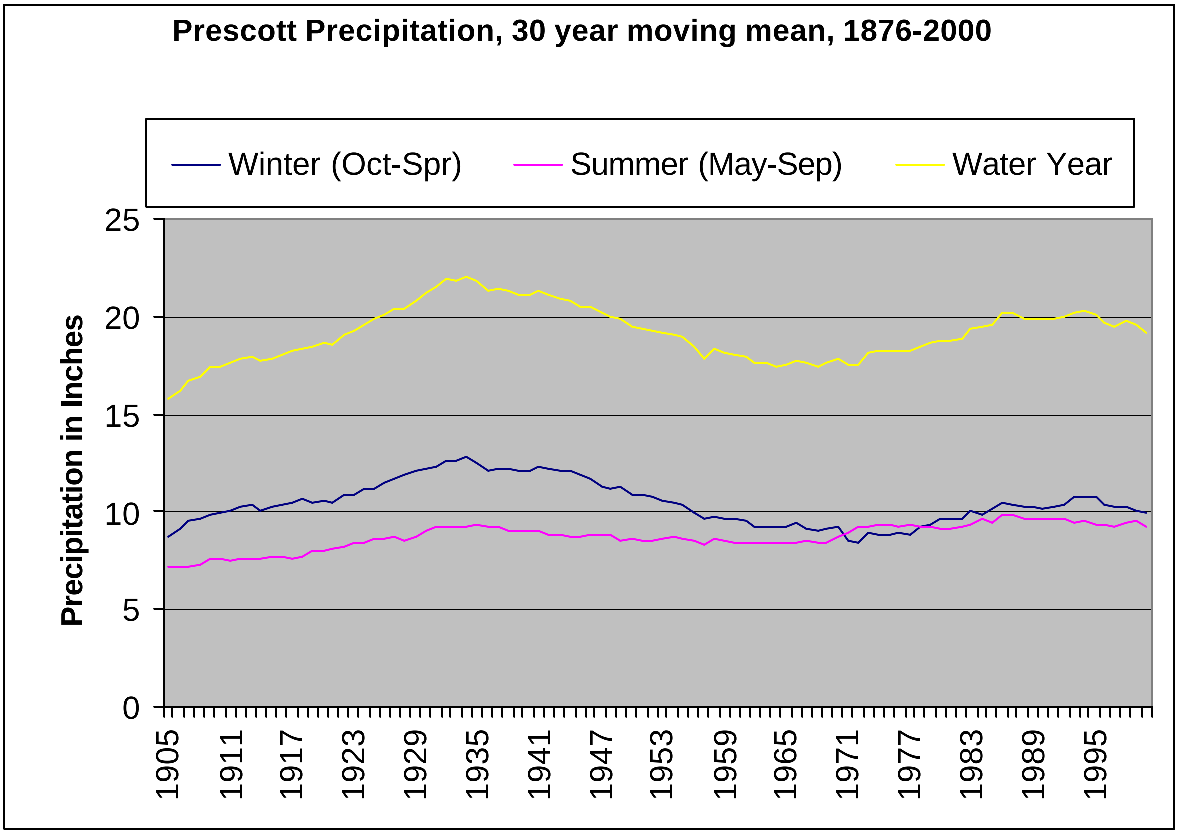


Fig. 4. Prescott Precipitation, Water Years 1876 - 2000



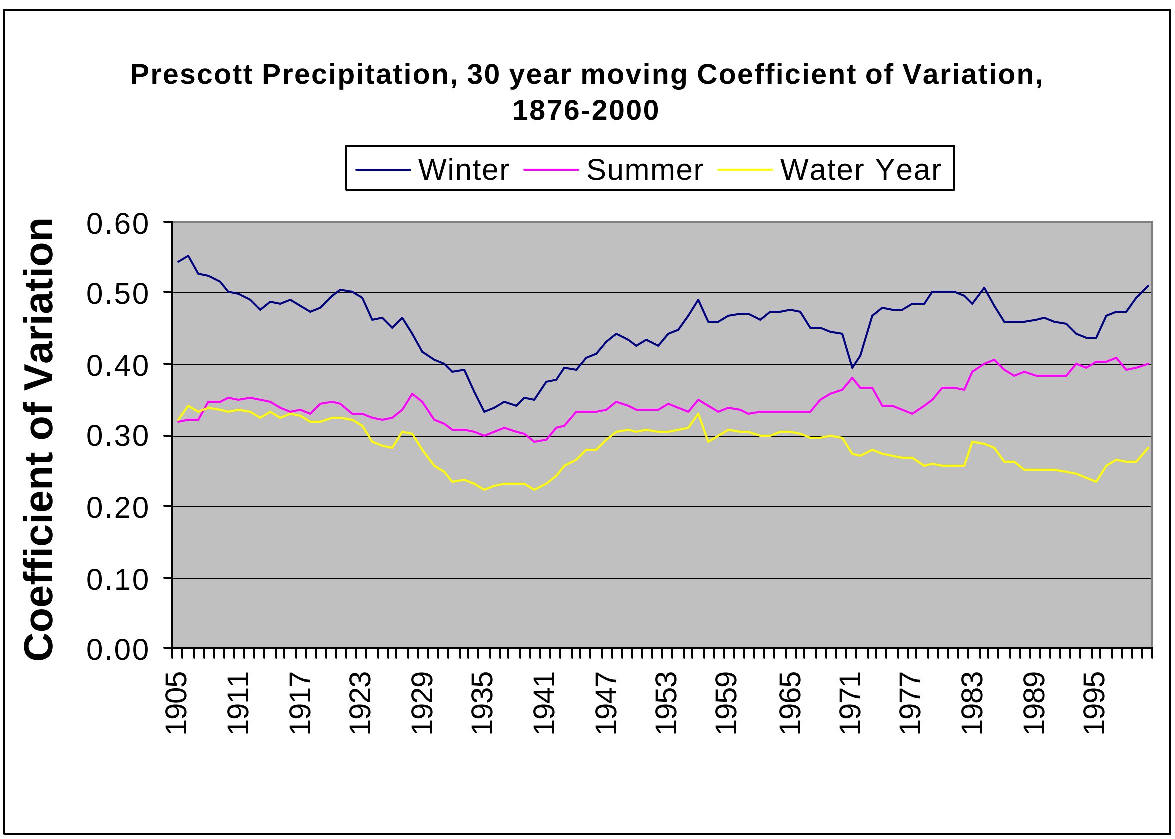


Fig.5. Prescott Precipitation, 30 Year Moving Mean and Coefficient of Variation.

years of record to a high of 21.88 for the 30 year period of 1903-32. Thirty year normals calculated on census years (using water year rather than calendar year) would have been:

1910	17.42 inches
1920	18.57
1930	21.24
1940	21.12
1950	19.43
1960	18.01
1970	17.84
1980	18.79
1990	19.80
2000	19.20

The coefficient of variation is also displayed. This is an index of the degree of variability around the mean, or average. It is calculated as the standard deviation divided by the mean. It shows the highest degree of variation for winter precipitation. There is a certain amount of compensation between summer and winter such that the variation of yearly precipitation is less than either winter or summer.

As Figures 4 and 5 show, the winter precipitation appears to be more “cyclic” than the summer precipitation. It is highest in the first third of the twentieth century, then declines through the middle part of the century, then rises again through the latter ¼ but does not reach the same level as the early part of the century. By contrast there does not seem to be as much change in the summer precipitation when averaged over a 30 year period and there appears to be a slight rise over time. However, caution is needed in interpretations of minor changes due to possible complications of moving the site of the Prescott precipitation gage within the community.

The variability of precipitation over a 30 year period is greatest for winter precipitation and least for summer. However, patterns are not as obvious as for mean amounts. The most obvious appears to be an increasing variability of summer precipitation in the latter part of the record. This may warrant further analysis.

The following table illustrates the relationship of temperature and precipitation with elevation for the 30 year period 1961-1990.

Station	Elevation in ft.	Mean Annual Temp	Mean Ann. Precipitation
Castle Hot Springs	1990	69.3° F.	15.33 inches
Cordes	3770	60.9 “	15.35 “
Prescott	5400-5210*	53.0 “	19.63 “
Crown King	6000-5920*	52.9 “	28.53 “
* Station location changed during period, beginning & ending elevations given.			

As the table illustrates, there are some apparent anomalies in the general relationship of temperature and precipitation with elevation. Crown King has an almost identical temperature with Prescott, even though it is about 600 feet or more higher in elevation. However, Crown King has nearly half again as much precipitation as Prescott. Castle Hot Springs has almost identical precipitation with Cordes, although there is 1800 feet elevation difference and there is a very significant difference in temperature. The location in relation to terrain may help explain this situation. Castle Hot Springs is on the southern edge of the Bradshaw Mountains where moisture laden air masses are beginning to be affected by the rising terrain and precipitation is induced. By contrast, Cordes is on the leeward side of the Bradshaw Mountains and air masses have already dropped much of the most precipitable moisture at higher elevations before reaching Cordes.

Figures 6 and 7 illustrate the monthly distribution of temperature and precipitation. Displays are by water year which is from October through September. This water year has been used in hydrology because of its greater significance for water analysis than the calendar year. In general the end of September is at, or near, the end of the growing season and soil moisture is at a lower level. Precipitation beginning in October may begin to fill the portion of the soil "reservoir" or capacity for moisture storage that has been drained. During the winter months there is less drain on the soil moisture for evapotranspiration by plants. Succeeding precipitation may fill the soil moisture reservoir and the surplus be available for water yield – either as ground water recharge or by interflow or surface runoff to channels.

Mean temperatures are calculated as the average of maximums and minimums. Lowest mean temperatures are in December and January, while July has the highest means. The average minimum temperature in January ranged from 21.9° F. at Prescott to 39.5° F. at Castle Hot Springs. In July the mean maximum temperature varied from 84.9° at Prescott to 102.6° at Castle Hot Springs.

As would be expected there are wide variations in timing of precipitation. The following table illustrates maximum daily and monthly precipitation amounts by seasons -- winter & monsoon – for several stations having such statistics displayed on the Arizona Climate web site.

MAXIMUM DAILY & MONTHLY PRECIPITATION AMOUNTS, AGUA FRIA WATERSHED

Station	Period of Record	Maximum Daily				Maximum Monthly			
		Winter Season		Monsoon Season		Winter Season		Monsoon Season	
		Inches	Date	Inches	Date	Inches	Date	Inches	Date
Castle Hot Springs	1961-2000	3.35	3/1/91	4	9/12/66	11.45	Jan-93	7.35	Aug-63
Cordes	1927-2000	3.74	11/11/78	3.59	9/5/76	8.38	Dec-65	8.62	Aug-63
Crown King	1916-94	7.10	12/31/48	5.31	8/29/51	16.75	Jan-93	16.95	Aug-51
Prescott	1898-2000	7.92	2/28/05	3.15	8/22/60	10.59	Feb-27	10.51	Aug-71

As might be expected, the stations with longest periods of records have experienced the highest amounts of daily and monthly precipitation in both winter and monsoon precipitation periods. In addition, the two stations with longest records – Crown King

Fig. 6. Mean Monthly Temperatures (1961-90)

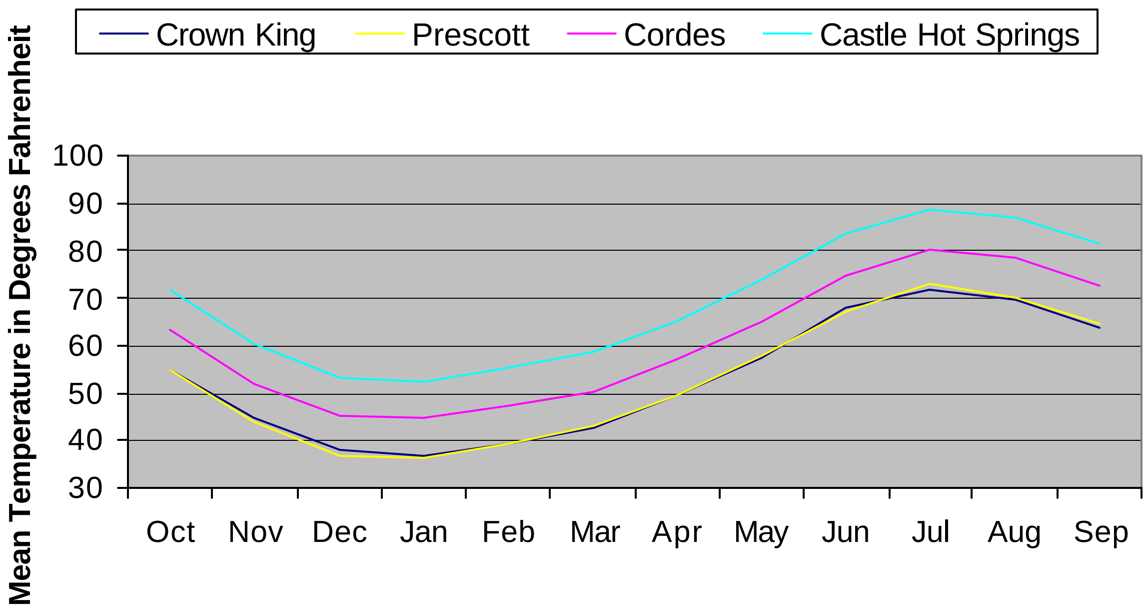
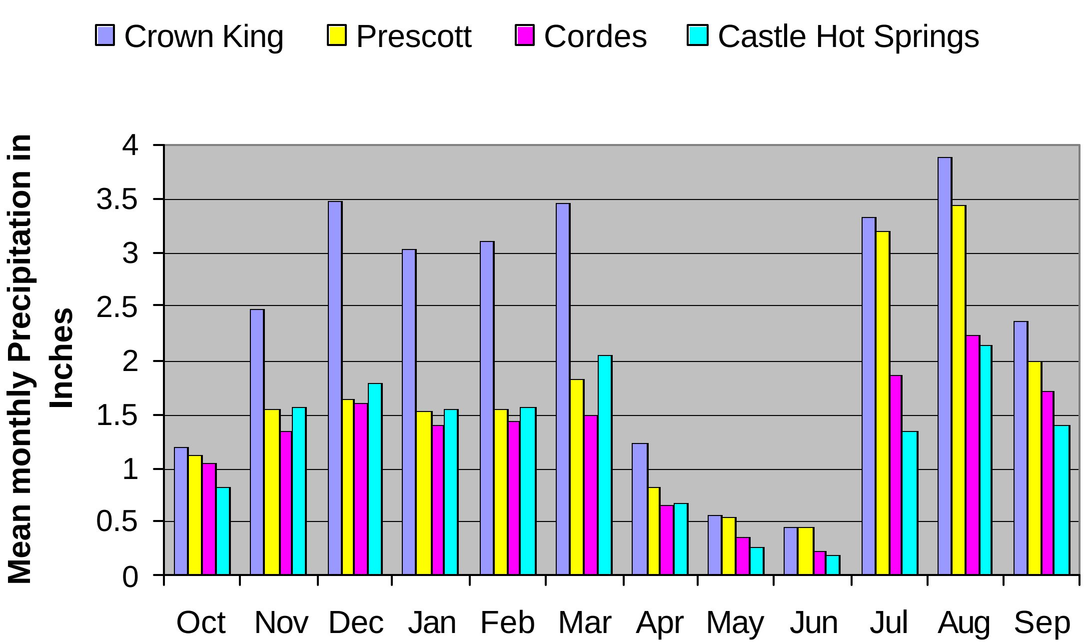


Fig. 7. Mean Monthly Precipitation 1961-90



and Prescott – are also the higher elevations and would be expected to have higher precipitation amounts. However, the highest winter monthly precipitation at Crown King was January, 1993, as at Castle Hot Springs. Of note is the Crown King monsoon season monthly precipitation of 16.95 inches in August, 1951. That same month Castle Hot Springs 4NW (which has a shorter period of record than Castle Hot Springs and is not included in the above table) recorded 14.89 inches. These two stations are the furthest south along the alignment of the Bradshaw Mountains and are more influenced by the orographic effects from tropical storms bringing in moisture masses from the south and southwest.

C. Geology

The geology of the area has been mapped at varying intensities. Portions of the western mountain ranges – Mingus Mountain and the Bradshaws – have been mapped more intensively because of the economic importance of the mineral resources and their historical development (see references and database lists). Data from the statewide map at a scale of 1:1,000,000 has been used to get acreages of surface geology. Table 3 displays acreages of major geologic types in the watershed. It is arranged from youngest to oldest rock types and is the same classification and map symbol as the geology map included in the appendix.

Table 3. Major Geologic Types in the Agua Fria Watershed from Statewide Map

Map	Type	Acres	Epoch	Description
Q	Surficial deposits	11,043	Holocene to middle Pleistocene	Alluvium in present day valleys and piedmonts, eolian deposits.
Qo	Older surficial deposits	625	middle Pleistocene to latest Pliocene	Alluvium with less abundant talus and eolian deposits.
Tb	Basaltic rocks	253,310	late to middle Miocene, 8 to 16 Ma	Units, such as the Hickey Formation, erupted after most mid-Tertiary volcanism and tectonism.
Tsy	Sedimentary rocks	48,366	Pliocene to middle Miocene	Units deposited during and after late Tertiary normal faulting, commonly capped by patches of Quaternary surficial deposits.
Tv	Volcanic rocks	69,884	middle Miocene to Oligocene; 15 to 38 Ma	Silicic to mafic flows and pyroclastic rocks; includes some subvolcanic intrusions.
Tsm	Sedimentary rocks	18,385	middle Miocene to Oligocene; 15 to 38 Ma	Deposited during mid-Tertiary orogenic activity in the Basin and Range Province and southwestern Transition Zone.
TKg	Granitoid rocks	4,137	early Tertiary to Late Cretaceous; 55 to 85 Ma	Generally metaluminous granite to diorite and subvolcanic porphyry.
MC	Sedimentary rocks	4,240	Mississippian to Cambrian	Redwall Limestone; Martin Formation, Tapeats Sandstone
Xg	Granitoid rocks	234,594	Early Proterozoic; 1650 to 1750 Ma	Granite, granodiorite, tonalite, quartz diorite, diorite, and gabbro; commonly foliated.
Xm	Metamorphic rocks	2,782	Early Proterozoic; 1650 to 1800 Ma	Undifferentiated metasedimentary, metavolcanic, and gneissic rocks.
Xms	Metasedimentary rocks	73,430	Early Proterozoic; 1650 to 1800 Ma.	Undifferentiated metasedimentary rocks
Xmv	Metavolcanic rocks	88,943	Early Proterozoic; 1650 to 1800 Ma.	Undifferentiated metavolcanic rocks
	TOTAL	809,740		

These 12 geologic types have been aggregated to five groups and are displayed in Figure 8. They are grouped from the statewide map as follows:

Surficial - Q and Qo
Basalt – Tb
Sedimentary – Tsy,Tsm,MC
Silicic Volcanic – Tv
Granitoid & Metamorphic – TKg, Xg,Xm,Xms,Xmv

Richard Wilson (1988) also groups some geologic types together and describes them and their significance to groundwater hydrology.

The granitoid, metamorphic, metasedimentary and metavolcanic rocks he groups together under the term, “basement unit”. He describes them as being “dense, nonporous, and nearly impermeable”. These make up a large part of the surface of the Bradshaw Mountains and of Mingus Mountain. The metamorphic group is located in the upper part of Mingus Mountain. On the Bradshaws it is along the crest and the northern portion. Large contiguous areas of granitoid rocks are on the lower, foothills portion of Mingus and the southern portion of the Bradshaws south of the Cleator-Crown King road. This group constitutes about half of the surface area and is at a relatively shallow depth below basalt flows on significant other areas. It contains the oldest rocks, much of it from formations which have been dated as 1.6 to 1.8 billion years old.

The next group discussed by Wilson is the “marine unit” of Paleozoic sediments (MC on the statewide map). It includes Tapeats Sandstone and Martin Formation, with some Redwall Limestone. These rocks “store and transmit water primarily in fractures, weathered zones, and solution cavities.” He displays it as being present underlying basalt flows, with limited surface outcropping on the some of the higher areas in the northeastern portion, e.g. toward Squaw Peak and Pine Mountain.

The areas shown on the statewide geology map as Tsy, or sedimentary rocks of Pliocene to Middle Miocene, are in the area mapped by Wilson as having the surface as “basin-fill unit” generally overlying a “sedimentary unit” in an area generally north of Cordes Junction and west of I-17. He describes the sedimentary unit as being a major aquifer in the northern part of the watershed with large amounts of water stored in it. It is described as being composed of cobble gravel, sand, silt, clay, marl & limestone weakly to moderately consolidated. It is interbedded with volcanic rocks at Mayer, Cordes, Spring Valley and Cordes Junction. He says that it underlies volcanic rocks near Cienega Creek, along Ash Creek, and near the Agua Fria River east and southeast of Cordes Junction. He describes this basin fill unit as the youngest and most transmissive unit in the northern part of the watershed, storing and transmitting large quantities of ground water. Recharge from ephemeral streams occurs in this unit.

The basaltic rocks of Tertiary age make up a large, generally contiguous, portion of the east side of the watershed. It includes Squaw Peak to Pine Mountain area and mesas such as Perry Mesa within the Agua Fria National Monument. Smaller areas are present to the

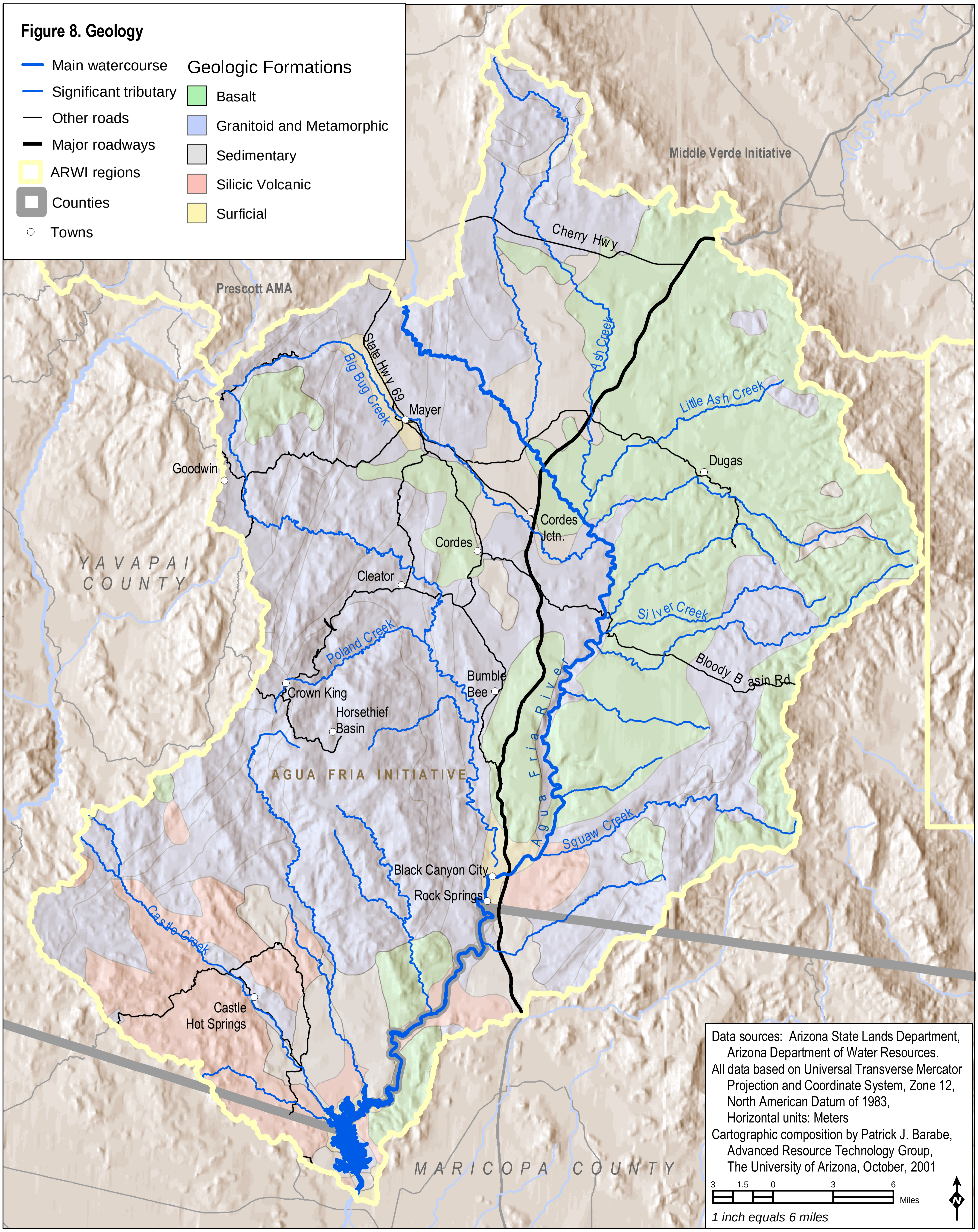


Figure 8. Geology
Main watercourse
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Geologic Formations
Basalt
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3 1.5 0 3 6
Miles
1 inch equals 6 miles
N

west, such as Big Bug Mesa, and to the south in the New River Mountains. Wilson decribes the unit as consisting of basaltic lava flows, cinder cones, tuff, and water-deposited interbeds of basaltic cinders and gravel. Flows are typically 10-50 feet thick, generally vesicular, and columnar jointing and fracturing are common. The volcanic sediments are described as containing abundant sand- and gravel-size particles but little silt and clay. Wilson says that in the Black Hills (north central and northeastern portion of watershed) they make up more than half the exposed thickness of the volcanic unit.

In the southwestern part of the watershed, primarily in the Castle Creek and Cottonwood Creek drainages above Lake Pleasant, is a substantial area of volcanic rocks of Tertiary age and described as silicic to mafic flows and pyroclastic rocks. The soil survey for the area described one of the more widespread soils as being formed on areas of andesite, tuff, and agglomerate. Numerous relatively short, steep sided drainages and a few long drainages characterize the area.

At the scale of the map used for the entire watershed, the only areas mapped as Quaternary alluvium are located around and including Lake Pleasant and the area around the confluence of Black Canyon Creek with the Agua Fria River, including Black Canyon City and Rock Springs, plus a strip along Big Bug Creek. More detailed mapping at a higher degree of resolution displays other areas of alluvium, e.g., Battle Flat near the crest of the Bradshaws west of Cleator.

The presence of faults and fracture zones has an effect on water movement, both acting as a conduit along them and often as an aquaclude (barrier) to perpendicular movement. Major faults have been identified, generally oriented in a north-south or north-northeast by south-southwest alignment. The Shylock slip fault zone is very apparent on satellite imagery and can be seen from just west of Black Canyon City extending northward to the southwest side of Mingus Mountain. Much of the metamorphosed rock in the fault zones is aligned with high angle foliation, e.g., the beds tend to run closer to vertical than horizontal.

D. Soils

Soils are the integrated result of geologic, climatic, and biotic influences over time. Information on soils is available for various portions of the watershed and in varying degrees of resolution. The entire watershed is included in statewide mapping coverage by the National Resource Conservation Service (NRCS) at a scale of 1:250,000 or approximately one inch on the map equals four miles. The majority of the watershed is covered with much more detailed inventories. The Prescott National Forest's Terrestrial Ecosystem Survey is mapped at 1:24,000, or 1 map inch equals 2,000 feet. A portion of the Tonto National Forest in the Agua Fria grassland area is also mapped at this scale. The lands which are Arizona State Trust, Bureau of Land Management, and private outside of National Forest boundaries are included in the NRCS' "Soil Survey of Yavapai County, Arizona, Western Part" with maps displayed on aerial photo mosaics at a scale of 1:32,560 or one map inch equals ½ mile.

In areas of irregular terrain the soils are often found in intricate patterns, such that mapping at the scale that has been done cannot adequately reflect on-the-ground detail. Soil mapping units may sometimes be associations - i.e., two or more different soils in a repeatable or predictable pattern such as on slopes and ridgetops or north and south slopes – or they may be complexes where arrangement is more random.

Soil characteristics most affecting the hydrologic cycle or watershed function include depth, texture, and structure. These in turn, along with presence of organic matter and vegetative material on and below the surface, affect the soil's infiltration capacity, permeability, and soil moisture capacity.

Geologic formation has a major effect on soil physical and chemical properties. For example, soils formed from the granitic formations tend to be coarser textured and less cohesive than those formed on basalts. That means that they have higher rates of water infiltration but are more vulnerable to surface soil erosion when not protected. The coarser textured soils – sandy loams, gravelly sandy loams, etc. – have less ability to hold water against the force of gravity than do the finer textured clay loams and clays.

One of the soil interpretations used frequently by hydrologists is Hydrologic Soil Group. Four categories are used – A through D. Group A has the highest rate of water infiltration and percolation and Group D the slowest. Soil depth is also factored into the classification as a very shallow soil might have a high rate of infiltration but very little capacity to hold water and thus would yield surface runoff after a relatively small amount of precipitation in a storm. The following table illustrates acreages of soil hydrologic groups cross referenced with vegetative type, based on characterization of soil hydrologic groups at the 1:250,000 scale map level. The table does not include any acreage of Hydrologic Group A soils. They are generally found in very gravelly alluvial bottoms and at this scale of mapping were not shown.

Table 4. Soil Hydrologic Groups in Relation to Vegetation

Soil Hydrologic Group	PETRAN MONTANE CONIFER FOREST	GREAT BASIN CONIFER WOODLAND	PLAINS & GREAT BASIN GRASSLAND	INTERIOR CHAPARRAL	SEMIDESERT GRASSLAND	AZ.UPLAND SONORAN DESERT SCRUB	TOTAL	
	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Percent
B	2,409	3,830	1127	29,944	176,048	26,655	240,013	30
C	489	29,709	600	49,485	28,294	14,611	123,189	15
D	17,384	3,363	0	191,319	38,020	196,451	446,537	55
TOTAL	20,282	36,903	1,727	270,748	242,361	237,718	809,740	100

E. Vegetation

Vegetation is interrelated with geology, soils, climate, fauna, and past disturbances -- both natural and human caused. There are a number of vegetative classification systems with the most widely used being of a hierarchical nature, e.g., successive levels of inventory for an area might be forest, coniferous forest, ponderosa pine, ponderosa pine-

Gambel oak. Information is available at a watershed level from several sources. The GAP satellite imagery was first used. Although it appeared to show greater precision, i.e., more detailed classification, checking indicated it had numerous inaccuracies and there was not a high degree of confidence. The map by Brown and Lowe, which is also available on a statewide basis, was used and is illustrated in Figure 9. More detailed information is available for the portion within the Prescott National Forest as a part of their Terrestrial Ecosystem Survey. Each mapping unit classifies and describes the vegetation present, including quantitative descriptions of species abundance and density. More detailed information is available for riparian areas because of their importance and limited area.

Acreages within the watershed by vegetative unit include:

Table 5. Vegetative Types

Vegetative type	Acreage	Comments
Petran Montane Forest	20,282	Ponderosa pine & associated species. Portions of upper Bradshaws, Pine Mountain, & Mingus Mtn.
Great Basin Conifer Woodland	36,903	Pinyon-juniper, primarily east and northeast edge on basalt soils
Interior Chaparral	270,748	Manzanita, shrub live oak and other shrubs. Large areas in Bradshaws and Mingus Mtn. and band below woodland on east side.
Plains, Great Basin Grassland	1,727	Very small area in northwest corner.
Semidesert Grassland	242,361	Large contiguous area in central & north-central part of watershed. Agua Fria grasslands are a part. Several riparian areas run through.
Upland Sonoran Desert Scrub	237,718	Variety of desert species, saguaro cactus is present in much of area. Several riparian areas run through.

Table 6. Vegetation Types by Geologic Group

VEGETATION TYPES BY GEOLOGIC GROUP, UPPER AGUA FRIA WATERSHED (excludes Prescott AMA)								
Geologic Group	Petran Montane Forest	Great Basin Conifer Woodland	Plains, Great Basin Grassland	Interior Chaparral	Semidesert Grassland	AZ Upland Sonoran Desert Scrub	TOTAL	
	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Percent
Surficial	0	0	0	857	2997	7813	11668	1.44
Basalt	2394	33362	0	43229	132975	41351	253310	31.28
Sedimentary	173	2086	203	4779	33048	30703	70991	8.77
Silicic Volcanic	0	0	0	4569	0	65315	69884	8.63
Granitoid & metamorphic	17715	1455	1525	217314	73341	92536	403886	49.88
TOTAL	20282	36903	1727	270748	242361	237718	809740	100.00

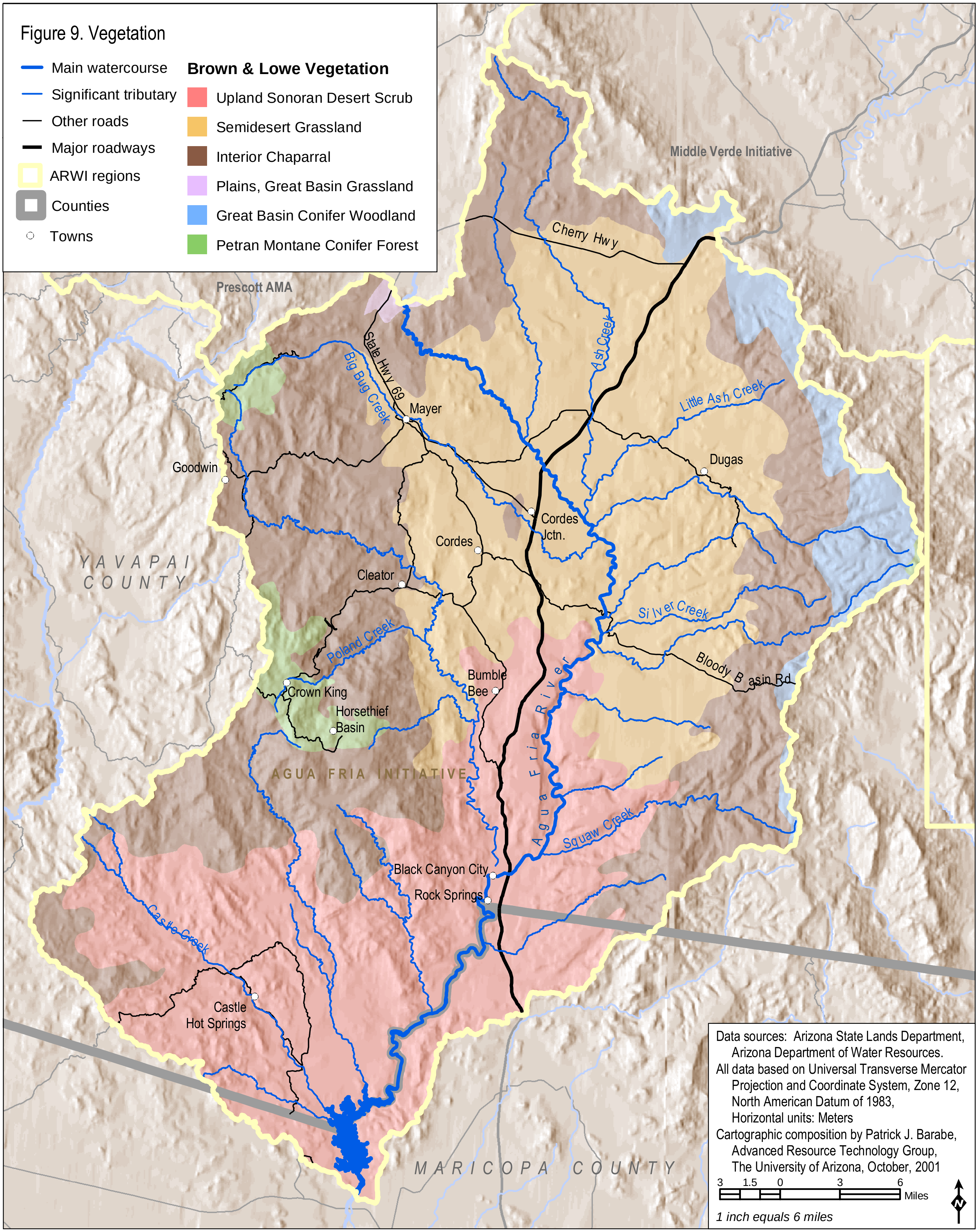
Figure 9. Vegetation
Main watercourse
Significant tributary
Other roads
Major roadways
ARWI regions
Counties
Towns
Brown & Lowe Vegetation
Upland Sonoran Desert Scrub
Semidesert Grassland
Interior Chaparral
Plains, Great Basin Grassland
Great Basin Conifer Woodland
Petran Montane Conifer Forest
Middle Verde Initiative
Prescott AMA
Cherry Hwy
State Hwy 69
Big Bug Creek
Ash Creek
Little Ash Creek
Mayer
Dugas
Goodwin
Cordes Jctn.
Cordes
Cleator
YAVAPAI COUNTY
Silver Creek
Poland Creek
Bloody Basin Rd
Bumble Bee
Crown King
Horsethief Basin
AGUA FRIA INITIATIVE
Agua Fria River
Squaw Creek
Black Canyon City
Rock Springs
Castle Creek
Castle Hot Springs
MARICOPA COUNTY
Data sources: Arizona State Lands Department, Arizona Department of Water Resources.
All data based on Universal Transverse Mercator Projection and Coordinate System, Zone 12, North American Datum of 1983, Horizontal units: Meters
Cartographic composition by Patrick J. Barabe, Advanced Resource Technology Group, The University of Arizona, October, 2001
3 1.5 0 3 6
Miles
1 inch equals 6 miles
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As shown, the woodland is found primarily on basalt and the chaparral predominantly on granitoid and metamorphics.

Brief summaries and descriptions with emphasis on relevance to hydrologic cycle follow:
1. Petran montane forest. The ponderosa pine occupies slightly more area than displayed on the map because of the scale employed. It is also found on some north slopes and canyon bottoms within the large contiguous area displayed as interior chaparral. It intergrades with adjacent chaparral in the Bradshaws and Mingus Mountain and with woodland in the Pine Mountain area. It is normally found where better moisture conditions are present. Ponderosa pine evolved with natural fire and grew in relatively open stands in much of northern Arizona prior to European settlement. Exclusion of fire has resulted in much more dense stands today that are more vulnerable to damage when fires do occur. A study in a small ponderosa pine stand surrounded by chaparral (Dieterich and Hibbert, 1988) found that pre-settlement fire frequency had averaged 1 fire every 2-3 years within the stand and individual trees sampled had been fire scarred on average every 4-10 years. However, the evidence of fires abruptly stopped when settlement began with mining in 1863.

Ponderosa pine generally provides a protective ground cover via litterfall under the tree canopy, in addition to grasses and other herbaceous vegetation where litter does not prevent establishment. Because it is generally present where moisture is less limited it yields more water than most of the other vegetation types within the watershed.

2. Great Basin conifer woodland. Pinyon-juniper is dominated by pinyon pine (*Pinus edulis* or *Pinus fallax*) and Utah juniper (*Juniperus utahensis*) growing in various combinations. It is commonly accompanied by both warm and cool season grasses growing in the interspaces between trees. Blue grama (*bouteloua gracilis*) is often the most common grass, along with sideoats grama, (*Bouteloua curtipendula*), squirreltail (*Elymus elymoides*) and three awn (*Aristida spp.)*. Shrubs and half shrubs such as broom snakeweed (*Gutierrezia sarothrae*) and skunkbush (*Rhus trilobata*) as well as some cacti such as prickly pear (*Opuntia engelmannii*) are also present. Studies in pinyon-juniper on basalt soils in the Beaver Creek watershed in the adjacent Verde basin found that water yield was primarily from major winter storms and occasional very high intensity monsoonal storms, and was considerably less than from higher elevation ponderosa pine. Removal of the pinyon-juniper overstory did not produce an appreciable increase in water yield. Erosion rates from these soils were relatively low, due to the combination of soil rockiness and protection, cohesiveness of the surface soil and relatively gentle slopes.

3. Interior chaparral. Chaparral is found on a variety of rock types but appears to be most adapted to soils developed from weathered granitic materials (Baker, DeBano, and Ffolliott, 1997). It is characterized by shrubs with evergreen leaves that are well adapted to heat and drought and which respond to fire by either sprouting rapidly or having accelerated seed germination. Shrub live oak (*Quercus turbinella*), mountain mahogany (*Cercocarpus betuloides*), manzanita (*Arctostaphylos pungens* and *Arctostaphylos pringlei*), silktassel (*Garrya wrightii* and *Garrya flavescens*), sugar sumac (*Rhus ovata*) are common components. Often the dense shrubs preclude any herbaceous understory

vegetation from becoming established. Rooting depths are commonly much deeper than for grasses and forbs, allowing the shrubs to withstand prolonged drought better than the grasses which are limited to the upper soil level. In the coarse textured, poorly developed soils from granite the plant available moisture storage capacity is quite limited, especially on shallow soils. Water which has percolated into cracks in the weathered upper portion of bedrock may be available to some shrubs but not to grasses, thus providing a competitive advantage during dry seasons.

It was previously believed that there were significant opportunities for increasing water yields by converting areas of chaparral to shallow rooted species such as grass and forbs. However, the most effective method of conversion – herbicides – has not been available to federal agencies for this use in a number of years. In addition, research has shown that such treatment results in an initial flush of both sediment and nutrients into local streamcourses until the chaparral vegetation is reestablished.

4. Semidesert grassland. This area includes the locally important Agua Fria grasslands, identified as important for its ecosystem benefits to a variety of wildlife species, most visibly the pronghorn antelope. The majority of this vegetation type within the watershed is on soils developed from basalt, with lesser amounts on Tertiary age sediments (Wilson's 'basin fill" unit) and some granitics. A number of grass species are present including blue grama, sideoats grama, black grama (*Bouteloua eriopoda*), tobosa (*pleuraphis mutica*), curly mesquite (*Hilaria belangeri*), western wheatgrass (*Pascopyrum smithii*), three awn (*Aristida spp.),* squirreltail, New Mexico needlegrass (*Hesperostipa neomexicana*), and vine mesquite (*Panicum obtusum*). Shrubs and some woodland species are present in varying degrees and locations including pinyon, juniper, catclaw (*Acacia greggii*), mesquite (*Prosopis velutina*), shrubby buckwheat (*Eriogonum wrightii*) plus some cacti, e.g., prickly pear and banana yucca (*Yucca baccata*).

The grassland is important for grazing of domestic livestock on land administered by the Bureau of Land Management, Forest Service, and Arizona State Land Department, as well as some which is private. Production of forage varies considerably from year to year depending on seasonal and annual precipitation.

5. Upland Sonoran desert scrub. This vegetation group occupies a variety of terrain and geologic types. The stately saguaro is common in portions, along with palo verde, mesquite, and a variety of shrubs and cacti, e.g., barrel, cholla, prickly pear, pincushion. Numerous grasses and forbs are present on local sites, including annual forbs which create colorful displays of flowers during wet springs. Herbaceous growth varies widely depending on precipitation.

The low precipitation results in a low density of vegetative plant cover. Much of the area has developed a protective armor of "desert pavement", which is an almost complete covering with rock material of various sizes, often as small as gravel. This protects the underlying soil material from raindrop impact.

6. Riparian areas. Although not shown at the scale of the vegetation map used for the watershed, a number of riparian areas along streamcourses have been mapped. The

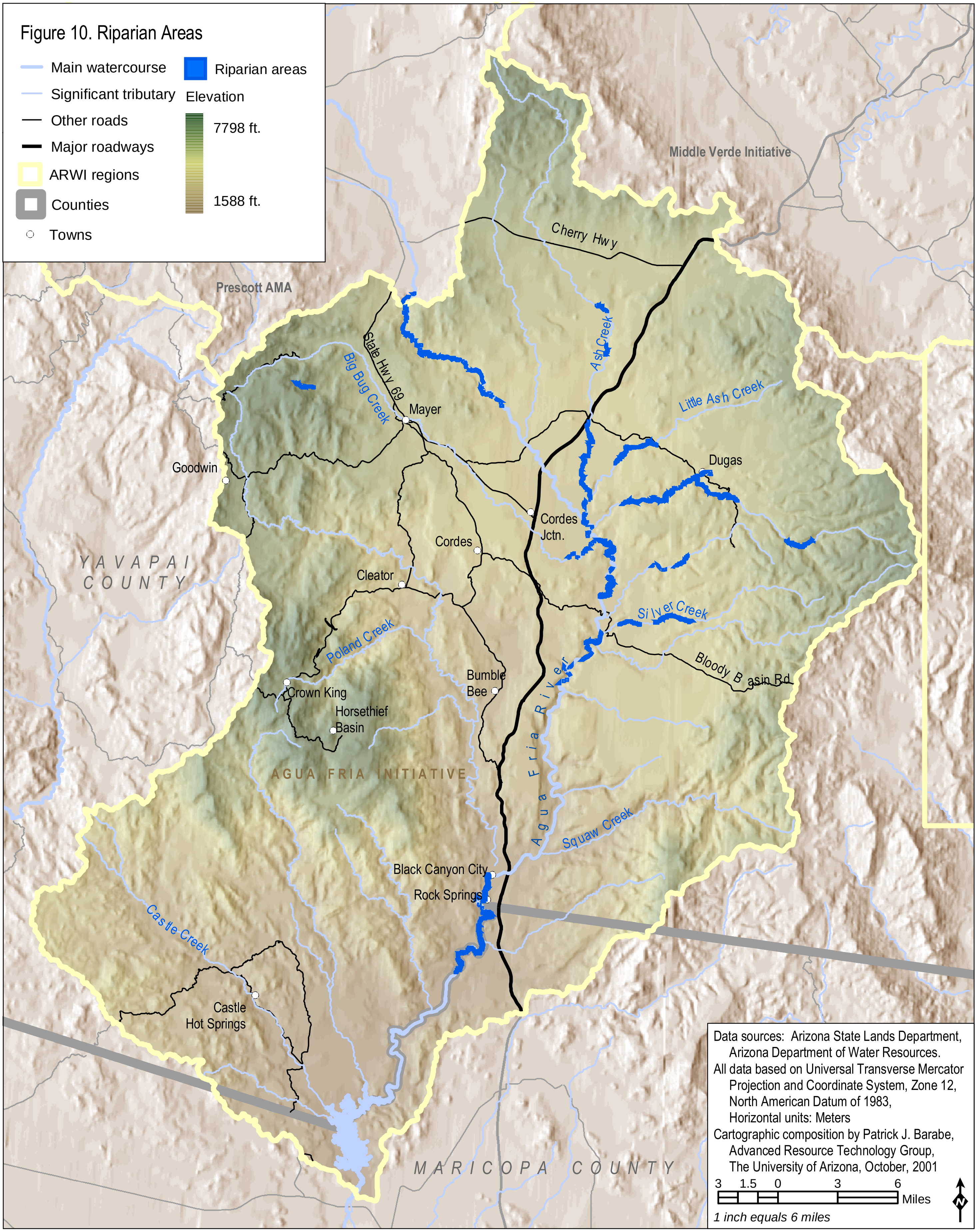


Figure 10. Riparian Areas
Main watercourse
Significant tributary
Other roads
Major roadways
ARWI regions
Counties
Towns
Riparian areas
Elevation
7798 ft.
1588 ft.
Middle Verde Initiative
Prescott AMA
Cherry Hwy
State Hwy 69
Big Bug Creek
Ash Creek
Little Ash Creek
Mayer
Goodwin
Dugas
Cordes Jctn.
Cordes
Cleator
YAVAPAI COUNTY
Silver Creek
Poland Creek
Bloody Basin Rd
Bumble Bee
Crown King
Horsethief Basin
Agua Fria River
AGUA FRIA INITIATIVE
Squaw Creek
Black Canyon City
Rock Springs
Castle Creek
Castle Hot Springs
MARICOPA COUNTY
Data sources: Arizona State Lands Department, Arizona Department of Water Resources.
All data based on Universal Transverse Mercator Projection and Coordinate System, Zone 12, North American Datum of 1983, Horizontal units: Meters
Cartographic composition by Patrick J. Barabe, Advanced Resource Technology Group, The University of Arizona, October, 2001
3 1.5 0 3 6
Miles
1 inch equals 6 miles
N

U.S.Fish and Wildlife Service has done a "National Wetlands Inventory" and produced maps that are either composites with, or overlays for, USGS 7.5 minute topographic maps. Information can be obtained at http://www.nwi.fws.gov/.

The Arizona Land Resource Information System (ALRIS) coverage of riparian vegetation is displayed in Figure 10. The data base for this coverage was queried and reported a total of 1562 acres or about two tenths of one percent of the watershed. Of this amount 64 percent, or nearly two-thirds, is classified as "mixed broadleaf", meaning that it is a mixture of species not readily mapped to greater intensity at that scale. These would include cottonwood (*Populus fremontii*), sycamore (*Platanus wrightii*), alder (*Alnus oblongifolia*), ash (*Fraxinus velutina*), boxelder (*Acer negundo*), walnut (*Juglans major*), willow (*Salix sp*), and several other species. The species composition is present in varying proportions depending on elevation and climatic regime, substrate (material available for plant roots to utilize), and water availability. Mesquite made up 12 percent, flood scoured areas (sandbars, gravel and cobble bars, etc. not dominated by vegetation) were 10 percent and strand provided the remaining 14 percent. Strand vegetation occurs in stream channels that are prone to scouring by flash flooding and typically have a mud, sand, or cobble substrate. Its vegetation is generally sparse and includes such species which readily colonize these areas such as desert broom (*Baccharis sarothroides*).

Although the ALRIS query did not report miles of riparian vegetation, an analysis was done by visual transfer and plotting on Arizona TOPO!©, calculating approximately 60 miles within the watershed. This equates to an average width of riparian areas of a little over 200 feet. The ALRIS inventoried riparian areas appear to be predominantly along perennial stream segments. However, more detailed inventories by Arizona Game & Fish Department, the Bureau of Land Management, Prescott National Forest and Tonto National Forest have identified many more miles of riparian streamcourses. For example, the BLM has inventoried 104 miles of riparian areas of which only 36 miles are along perennial streams.

Survey protocols for inventory have generally been slightly different, with different degrees of detail for the different agencies. The section on watershed health, under hydrology, provides more details on survey results.

F. Land Uses

1. Livestock grazing. The land use most widespread across the area is livestock grazing. Beginning in the late 1800's following early settlement a number of ranches were developed. Usually based around a homestead of private land – commonly containing a water source – extensive areas of open range were used for grazing. It was well into the 20th century before individual allotments were assigned and fenced on the National Forest portion of the watershed.

The Agua Fria grasslands received greater livestock use than the Bradshaw Mountains due to terrain and vegetation. However the use was not as early or intensive, e.g., not as heavily stocked, as the adjacent Verde Valley due to less available water and further distance from military posts which provided early protection for settlers. Use peaked in the early 1900's and included cattle yearlong plus sheep driveways used for spring and fall trailing between the Salt River Valley and the Mogollon Rim. In the early 1900's up to 300,000 sheep would travel through the area (Rosebrook, 1994). As recently as 1960 up to 100,000 sheep used the driveways annually and in 1980 there were still about 20,000. In 2002 there are only about 4,000. Before fencing of individual allotments on National Forest in the 1930's, cattle were sometimes trailed for long distances to find rangeland with forage, e.g., from the Cienega Creek area to the vicinity of Black Canyon City (McPhee, 2002).

Early use in the Bradshaws was often associated with small mining operations scattered throughout the range. A few cows for milk and beef, along with horses were kept. Goats were herded in some areas, such as Battle Flat. The rugged terrain and dense brush vegetation made rounding up cattle difficult with the result that there were a number of wild cattle present. The granitic soils resulted in earthen stock tanks being less reliable water sources than on the basalt soils of the grasslands.

Beginning in the 1930's the Soil Conservation Service (now the Natural Resources Conservation Service) provided technical assistance for private land owners upon request and local Soil Conservation Districts (now Natural Resource Conservation Districts – NRCD's) provided a means for participation and leadership by local landowners interested in conservation practices. Following World War II, and continuing to the present, federal cost sharing programs assisted in installation of certain improvements for range management including some water developments and erosion control features. Assistance varied from technical assistance and engineering to actual reimbursement for a portion of the costs incurred.

Under the Arizona State Constitution State Trust lands are to be used to generate maximum revenue for certain designated educational and institutional beneficiaries. Grazing leases are issued for a maximum 10 year term. Lessees are encouraged to work with local NRCD's and incorporate grazing management on State Trust land with the intermingled private or public land on which they also graze livestock.

For the last several decades more intensive management of livestock through smaller pastures and more closely spaced waters has been emphasized. Various applications of principles of rest-rotation grazing, deferred-rotation grazing, etc. have been implemented. The objectives are to consider the impacts of grazing on plant physiology and to allow enough rest at appropriate times for desired plants to maintain root reserves, establish new plants, and provide soil surface protection from raindrop impact and soil erosion, while still harvesting forage. In the late 1980's a new system – "Holistic Resource Management" – was introduced and implemented on a few ranches. This involves goal setting, detailed planning, intensive monitoring, adjusting, and replanning. It has often included more and smaller pastures, as well as shorter periods of grazing in individual pastures. Within the watershed this system has been implemented on an area with grazing by the Orme Ranch.

2. Other agriculture. Agriculture with cultivated crops is quite limited within the watershed. Analysis of satellite imagery taken in 2000 was done by Yavapai County Water Coordinator John Munderloh. It revealed a total of 347 acres in 26 separate polygons which appeared to then be irrigated and 132 acres in 32 polygons which appeared to have been previously irrigated. Most are along the primary drainages of Agua Fria River and Ash Creek.

3. Mining. The lure of gold and other valuable minerals first drew European settlers to the area in 1863 with discoveries in the Walker Creek drainage tributary to the Agua Fria (currently within the Prescott AMA portion). Both the Bradshaws and Mingus Mountain have geologic formations containing ore of gold, silver and associated minerals. Miners spread across the area prospecting, filing claims, sinking shafts, and working a number of mines. Some of the highest density of workings was in the Crown King area where a number of mining operations were centered. Mining and related economic activities led to development of the Bradshaw Mountain Railway which reached Crown King via Cleator in 1904 but was abandoned and removed by the late 1920's (Bruce Wilson, 1990). Wilson's history of Crown King and the southern Bradshaws gives details on many of the numerous mining ventures and developments and the people associated with them.

Miners needed wood – to reinforce and stabilize mine shafts, for ties for rail cars in shafts, and for cooking and heating. Available wood was hauled considerable distances to support the various prospecting and mining efforts, including pine, oak and juniper. This occurred on Mingus Mountain, as well as on the Bradshaws.

4. Open space and recreational. As a large majority of the watershed is public land managed by the Forest Service and the Bureau of Land Management (BLM), public recreation is a major land use. There are a few developed campgrounds and a small lake in the Bradshaws in the Horsethief Basin area. However, the majority of recreation use is classified as dispersed use. This includes hiking, camping, hunting, viewing nature (e.g., birdwatching), photography, rockhounding, etc. Recreational gold panning is a pursuit in some drainages in and adjacent to the Bradshaws, with mining claims held by clubs for that purpose in several locations.

There are two areas on the Prescott National Forest which are part of the national wilderness preservation system. The Castle Creek wilderness includes 25,517 acres of very rugged terrain on the east slopes of the Bradshaws. The Pine Mountain Wilderness is on the east edge of the watershed and comprises about 20,100 acres of which a portion is outside the watershed and on the Tonto National Forest.

The Agua Fria National Monument was designated by presidential proclamation in early 2000 and is managed by the BLM. Information describing the monument and photographic views are available at: http://www.az.blm.gov/fr_nlcs.htm
Highlights include:

> "The 71,100-acre Agua Fria National Monument contains one of the most significant systems of prehistoric sites in the American Southwest. At least 450

prehistoric sites and four major settlement areas are known to exist within the monument. This area contains two mesas - Perry and Black Mesa - and the Agua Fria River Canyon. In addition to its rich record of human history, the monument contains a diversity of vegetative communities, pristine riparian habitat, topographical features, and a wide array of wildlife. Elevations range from 2,150 to 4,600 feet.

The majority of public land in the area was acquired around 1990 from the State of Arizona and in two private exchanges. The area contains most of a National Register of Historic Places District. Originally designated in 1975, the District was expanded in 1996 to encompass approximately 50,000 acres managed by the BLM and the Tonto National Forest. It is one of the largest prehistoric districts listed on the National Register of Historic Places. The area also contains all of the Perry Mesa Area of Critical Environmental Concern (ACEC), designated in 1987 to protect its cultural resource values. It also encompasses the Larry Canyon ACEC, which was designated in 1987 to protect a rare, pristine riparian deciduous forest within a desert ecosystem. The documentation supporting the nomination to the National Register and the ACEC designations identified many objects of scientific and historic interest within the monument area."

Planning for management of the Agua Fria National Monument began in late 2001 and includes extensive public participation. Additional inventories and analysis are underway. Planning is expected to take a couple of years. In addition, updates to the Resource Management Plan for the BLM land on and near the Bradshaws will be included.

A portion of the Agua Fria River between its confluences with Sycamore Creek and Larry Canyon was evaluated for its suitability for the National Wild & Scenic River System by the BLM in 1993. The suitability assessment recommended that two segments comprising 12.1 miles be considered as suitable for inclusion as "Scenic" and a middle section of 10.3 miles be considered as suitable for inclusion as "Wild".

A use which has been growing is off highway vehicle (OHV) use. Using four wheel drive pickups or SUV's, all terrain vehicles, or specialized motorcycles ("dirt bikes) many people enjoy this form of recreation by riding on primitive roads and trails as well as in areas which are off designated roads and trails. Often the purpose is a means to reach areas unavailable by roads. However, for many it is the pleasure and challenge of using a machine to traverse difficult terrain or recreate in an area away from access by normal vehicle. Washes and streamcourses – both perennial, e.g., portions of the Agua Fria, and ephemeral – are often used as areas for this use. Repeated and/or concentrated OHV use is causing damage to riparian vegetation in some areas.

5. Urban and residential. Yavapai County has been one of the fastest growing non-metropolitan counties in the United States. The 2000 census showed a population level twice that projected in the county's general plan done in 1975. Although there are no

incorporated communities within the watershed, community plans have been completed for:

> Black Canyon City Community Plan Update, 1986; Amendment, 1991
>
> Cordes Lakes Spring Valley, Highway 69 Corridor Community Plan, 1995
>
> Community Plans in the 1975 Yavapai County General Development Plan, including Mayer [less detail than the later community plans)

Former working ranches and farms have been converted to residential use in a variety of ways. Some which are adjacent to existing communities or transportation corridors have been developed in planned communities, e.g. Spring Valley and Cordes Lakes in the late 1960's-70's in the Highway 69 Corridor area. However, throughout Yavapai County a very large amount has been developed through lot splitting – a parcel can be split into any number of pieces as long as the result is parcels of at least 36 acres. In addition, parcels can be split into five pieces and the owners of the new pieces can again resplit until the parcels reach the miminum size for zoned designated uses. In much of the county this is 2 acre minimum per residence. Developments through lot splitting do not require development of infrastructure such as water and wastewater treatment systems. The updated Yavapai County General Plan (Dava & Associates, 2001) explains:

> "…a large percentage of land development in Yavapai County is unplanned. In the 12-month period from April 2000, to April 2001, there were 1,760 split parcels recorded in Yavapai County. During the same period, only 206 lots were platted as part of an approved subdivision or planned area development."

Population figures from the 2000 census are available in varying manners for areas which include unincorporated communities. For broad areas they are available in county census districts, or subportions of counties. They are also available for "census designated places" (CDP's) which include Mayer, Spring Valley, Cordes Lakes, and Black Canyon City. In addition, they can be retrieved by U.S. Postal zip codes. Zip code 86333 which includes Mayer, Spring Valley and Cordes Lakes, listed a population of 4,991 with a median age of 45.4. Zip code 85324, which includes Black Canyon City, listed a population of 2,747 with a median age of 47.5.

The 1996 Cordes Lakes/Spring Valley/Highway 69 corridor plan projects a potential for a total of 6,000 residential units (an increase of about 2,000) with the current zoning pattern, and a population of 12,000-15,000. This assumes continuation of the rural zoning (2 acres/residence) on most of the large tracts of existing private land.

The Arizona Department of Economic Security makes long range forecasts of population. The most recent forecasts were done in 1997 and are displayed for Mayer and Black Canyon City. However, by the 2000 census they were already below the actual population counted.

Year	**1997**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Black Canyon City CDP	2,227	2,407	2,722	3,046	3,368	3,680	3,968	4,219

Mayer	1,205	1,277	1,402	1,531	1,660	1,785	1,900	2,000

G. Hydrology

1. Water yield. Water yield which reaches the mouth of the watershed, or Lake Pleasant, is illustrated in Figure 11. This amount is derived from a combination of USGS stream gage measurements, calculations from lake water balances, and estimates based on a regression analysis with the gage near Rock Springs. As it shows, there have been wide fluctuations from year to year and decade to decade in the amount of water which reaches the reservoir site. Over the period 1912 to 2000 water year inflow ranged from a high of 481 thousand acre feet in 1916 to a low of 2700 acre feet in 1977, or a factor of 177 times. The mean flow for this 89 year period is about 83 thousand acre feet or an average yield of about 1.1 inch over the entire watershed (including the portion within the Prescott AMA). However, the median flow, or that which would be exceeded 50 percent of the time is only about 39 thousand acre feet or a ratio of mean to median of about 2.1. The following table gives a comparison of this variability for the same time period to streamflow of the Verde River and to precipitation at Prescott, both yearly and winter. The presence of perennial base flow in the Verde and no perennial base flow in the Agua Fria at Lake Pleasant is a very major difference.

AGUA FRIA AT LAKE PLEASANT STREAMFLOW VARIABILITY COMPARISON

Water Years 1912-2000

	Agua Fria Streamflow	Verde River* Streamflow	Prescott Winter Precip	Prescott Yearly Precip
Mean/Median	2.12	1.26	1.14	1.0
Max/Min	185	11.8	8.22	4.09
Coeff Variation	1.32	0.67	0.45	0.27

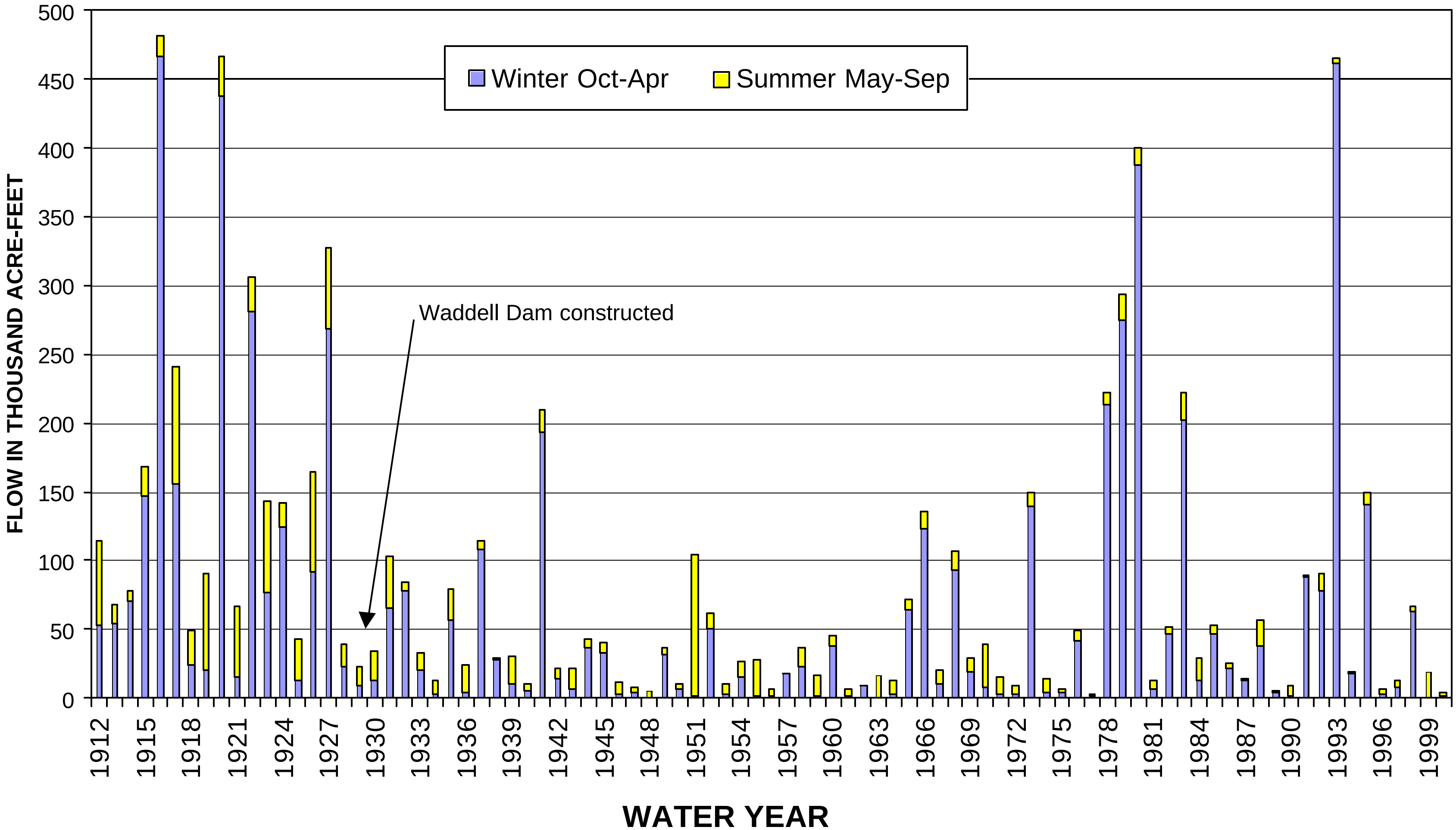
*Verde River below Tangle Creek after 1945. Verde River below Bartlett Dam prior to that date (dams built in 1939 and 1945). Analysis indicated little difference in water yield between the two areas.

Note: The coefficient of variation is the standard deviation divided by the mean and thus is a dimensionless index of variability.

Table 7 lists the streamflow gages within the watershed. Figure 12 is a map of the watershed, including the physical watershed within the Prescott Active Management Area, illustrating locations of stream gages and watershed boundaries associated with the gages. Figure 13 displays the time periods of the gages in perspective with the water yield at Lake Pleasant for the period for which data has been obtained. In addition to these, there are several peak flow gages, measuring periodic peak flows from relatively small watersheds. There are also periodic point-in-time measurements, primarily for

Fig. 11. AGUA FRIA RIVER STREAMFLOW AT LAKE PLEASANT

Data from USGS, Maricopa Co. Munic. Water Cons. Dist. No. 1, Central AZ Project., & Bureau of Reclamation



TOPO! map printed on 05/31/02 from 'Arizona.tpo' and "Untitled.tpg"

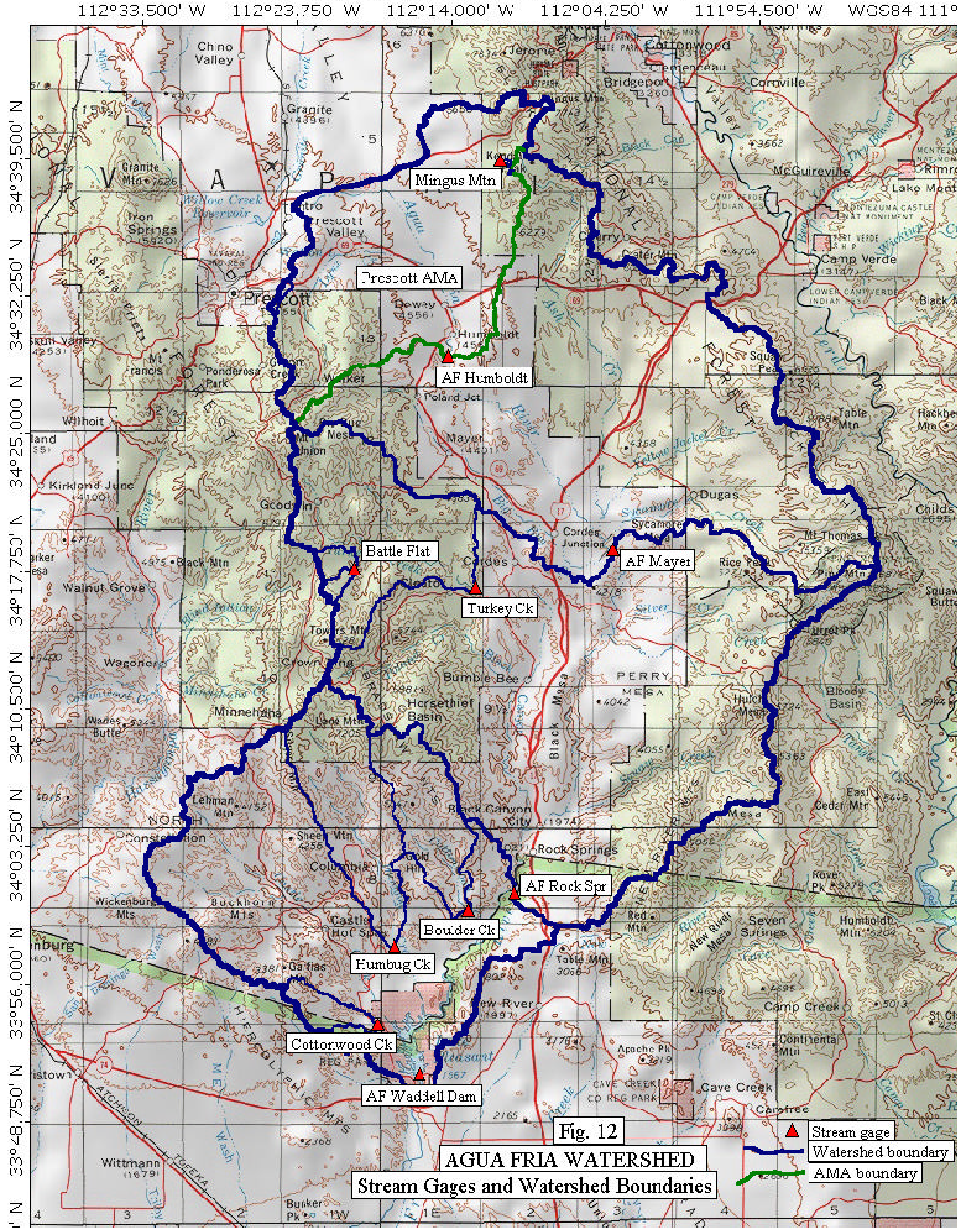
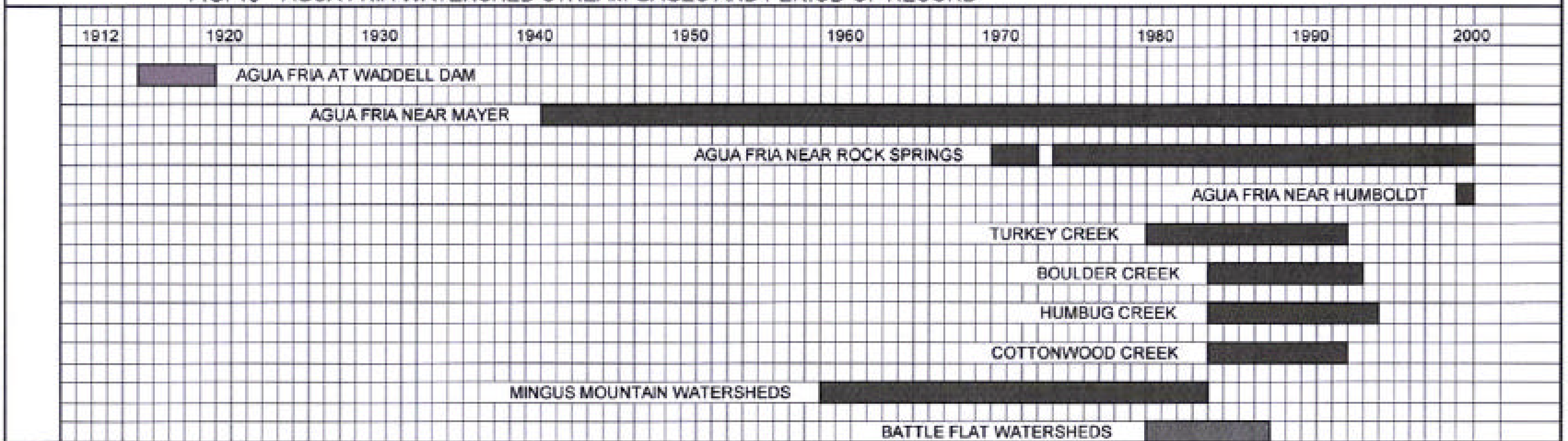
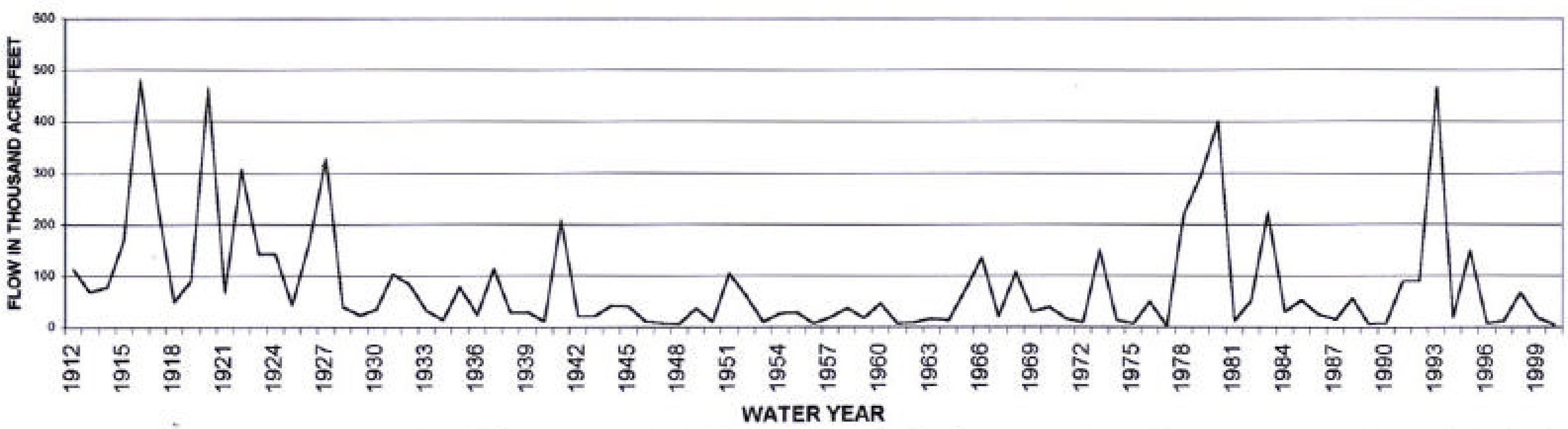


Fig. 12
AGUA FRIA WATERSHED
Stream Gages and Watershed Boundaries

FIG. 13 AGUA FRIA WATERSHED STREAM GAGES AND PERIOD OF RECORD



AGUA FRIA STREAMFLOW AT WADDELL DAM SITE (LAKE PLEASANT)*



* Although USGS stream gage at Waddell Dam present only 1915-1919, streamflow has been reconstructed from reservoir operations and other information.

periods of base flows. Several of these were done by BLM hydrologists on streams primarily within what is now the Agua Fria National Monument. Base flow measurements were made in two different seasons in WY 1981 for a number of small streams as a part of the Wilson (1988) study. Between 1981 and 1997 a number of measurements were taken on the Agua Fria River near the outlet of the Prescott AMA.

Table 7. Stream Gages within the Agua Fria Watershed

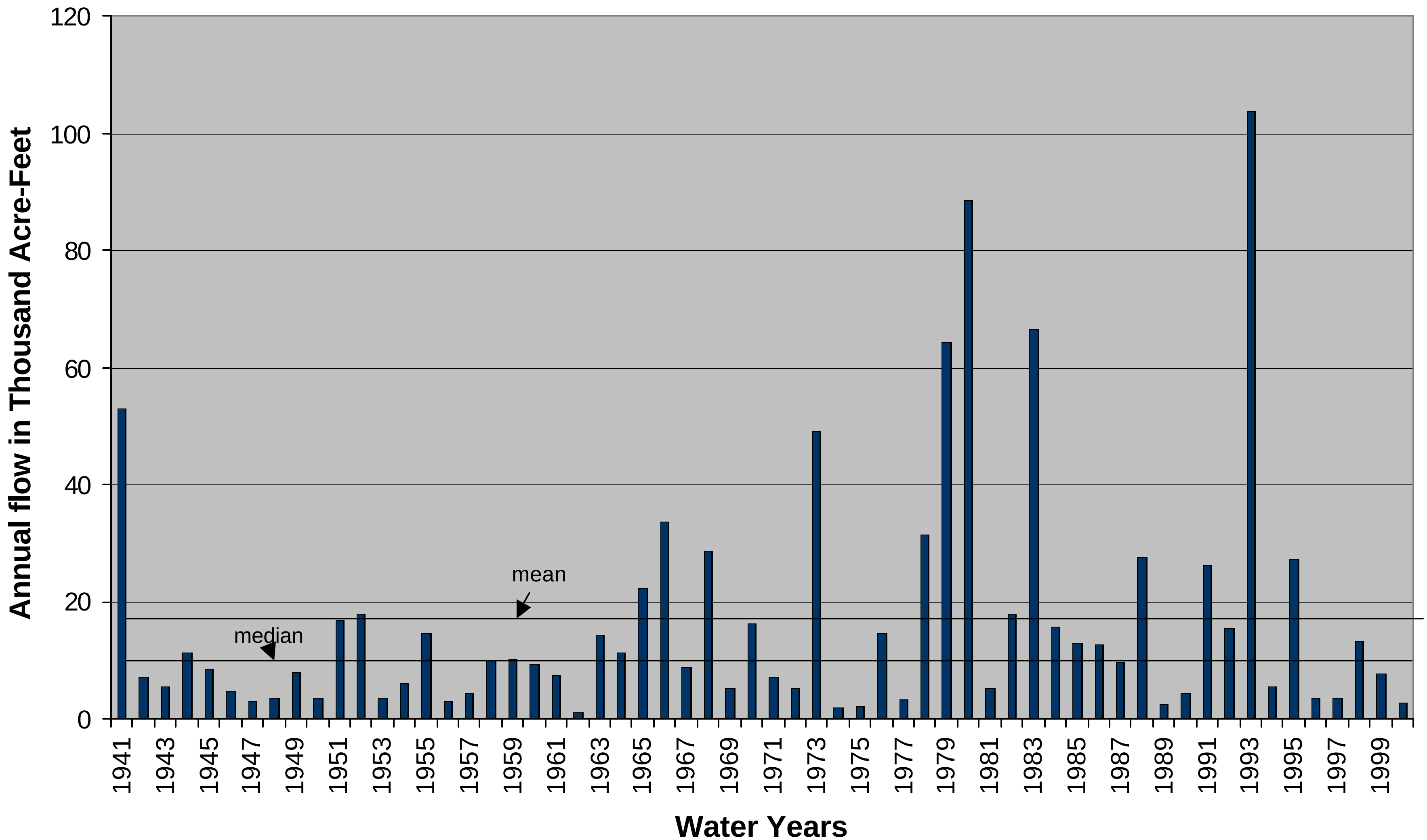
Name	USGS No. 095___	Drainage Size Sq miles	Period of Record	Comments
Agua Fria nr. Humboldt	12450	173	Jan 2000 to present	At outlet of Prescott AMA
Agua Fria nr Mayer	12500	585	Jan 1940 to present	Perry canal diversion just upstream for many years affected low flow.
Agua Fria nr Rock Spgs	12800	1110	Jan 1970 to present	No data WY 1974 site moved at start of WY75, low flows not equivalent
Agua Fria at Waddell Dam	13000	1459*	Oct 1914 to Sep 1919	
Turkey Creek nr Cleator	12600	89.4	Oct 1979 to Sep 1992	
Boulder Creek nr Rock Spr	12830	37.8	May 1983 to Sep 1993	
Humbug Creek nr Castle Hot Springs	12860	59.9	May 1983 to Sep 1994	
Cottonwood Creek nr Waddell Dam	12970	9.28	April 1983 to Feb 1993	
Battle Flat & Tuscumbia	**	.025 to 3.6	1979 to 1987	2 larger watersheds, 9 subwatersheds
Mingus Mtn. Watersheds	**	.07 to .15	1958 to 1983	3 watersheds, 2 treated

*Reported by USGS. Data base calculation via GIS of 1438. USGS figure used for calculation of areal water yield.

** U.S. Forest Service, Rocky Mountain Research Station

Figure 14 illustrates streamflow at the Agua Fria near Mayer stream gage (located just below the confluence of Big Bug Creek) for the 60 year period of water years 1941-2000.

Fig. 14. Agua Fria near Mayer Streamflow, Water Years 1941-2000



As illustrated in Figure 14, a relatively few very high years cause the mean annual streamflow over the 1941-2000 period to be considerably higher than the median.

For comparison to precipitation, the following is a comparison of the same period used for “normals” for precipitation –1961 to 1990 -- with other periods available. Flows are in thousand (M) acre feet.

TIME PERIOD EFFECT ON STREAMFLOW STATISTICS, AGUA FRIA NR MAYER & AT LAKE PLEASANT								
	Mayer				Lake Pleasant			
Period of Record	Mean	Median	Mn/Med	Coef Var	Mean	Median	Mn/Med	Coef Var
Water Years	M Ac-Ft	M Ac-Ft	Ratio	Ratio	M Ac-Ft	M Ac-Ft	Ratio	Ratio
1912-2000					82.0	39.7	2.07	1.32
1941-2000	16.8	9.5	1.77	1.23	62.9	24.3	2.59	1.49
1961-1990	19.8	12.8	1.55	1.09	69.5	24.3	2.86	1.41
1971-2000	21.8	12.8	1.70	1.22	85.6	24.3	3.52	1.42

It is noteworthy that in successive overlapping periods the median does not change as much as the mean, e.g., the median for Lake Pleasant inflow for 1961-1990 is 24.3 thousand acre feet per year. In moving to the 1971-2000 median the 10 years 1961-70 are dropped and the years 1991-2000 are added. Both the 10 year period dropped and the period added each have five years below and five years above 24.3 thousand acre-feet and no years that are closer to the years bracketing it (years of 23.2 and 25.3 thousand acre-feet).

The water yield per unit area commonly varies inversely with size of watershed. That is, the higher elevation headwaters of the watershed tend to have a higher yield per area and as the watershed becomes larger, the lower elevations tend to reduce the overall watershed average. However, this situation is reversed when comparing the watershed areas for the 1971-2000 period when information was available for the Rock Springs gage.

Watershed	Mayer	Rock Springs	Lake Pleasant
Watershed size- square miles	585	1,110	1,459
Mean yield in inches	0.70	1.04	1.10

Similar relationships were found by comparing Mayer and Lake Pleasant for the common record period of 1941-2000.

Because the gages for the small watersheds all have much shorter periods of record an adjustment was made to compare to the same time period for the Rock Springs gage.

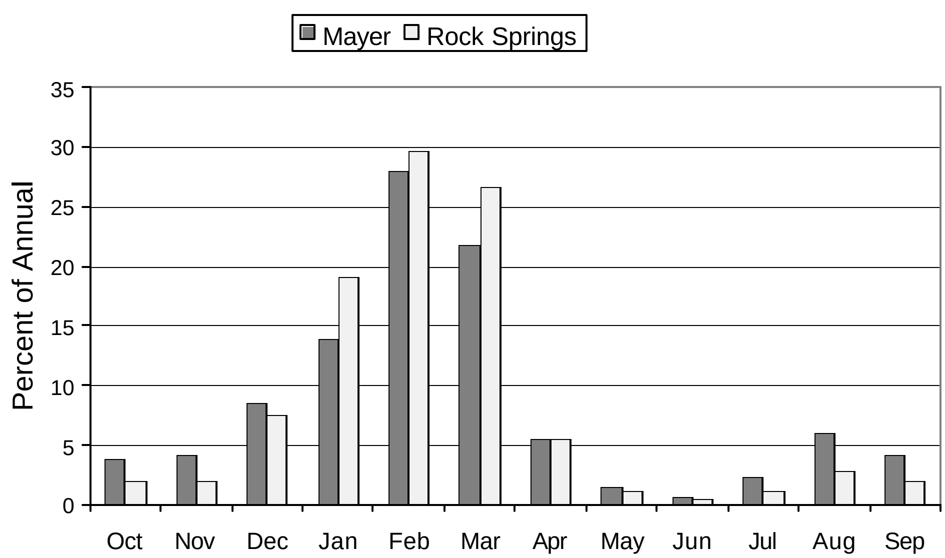
Gage	Watershed size square miles	Record Period water years	Mean for Period Inches	Adjusted to Rock Spr 70-00
Turkey Creek	89.4	1980-92	1.69	1.82
Tuscumbia	2.12	1980-87	3.05	2.79
Battle Flat	3.60	1980-87	1.48	1.37
Boulder Creek	37.8	1984-93	1.89	1.76
Humbug Creek	59.9	1984-94	1.54	1.55
Cottonwood Creek	9.28	1984-92	0.51	0.94
Mingus Mtn. C*	0.07	1971-83	1.02	0.82

*Mingus Mountain Watershed C was untreated control. Watersheds A and B received vegetation treatments in 1974 causing temporary increases in water yield.

Both Tuscumbia and Battle Flat are located within the Turkey Creek watershed. Humbug Creek, Boulder Creek, and Turkey Creek all have their headwaters at the top of the Bradshaws at elevations of 5600 to 7800 feet. By contrast, Cottonwood Creek is immediately west of Lake Pleasant and has a maximum elevation of about 3650 feet.

Time distribution of runoff is generally parallel to precipitation. Figure 15 illustrates percent of annual runoff by month for the Mayer and Rock Springs gages for the 1971-2000 period. As the figure shows, the majority of average annual runoff occurs in the winter months of January to March with the least being in May and June. The difference is more pronounced for the Rock Springs gage as it has minimal benefit of base flow compared to the Mayer gage.

Fig. 15. Monthly Distribution of Streamflow, 1971-2000



2. Base Flow. Base flow is what maintains perennial, or almost perennial, flow in segments of streams. The Arizona Department of Water Resources reports perennial stream reaches in the Agua Fria River for 21 miles (in four separate segments) plus 38 additional miles in 6 tributary streamcourses. Inventories and surveys by the Forest Service and BLM have identified 11 additional streams with segments being perennial. The BLM riparian database includes miles of stream by segment, classified by type of flow. Of approximately 104 miles of riparian area surveyed, 36 miles were perennial and 32 were intermittent, with the remaining 35 miles being seasonal, or ephemeral. The locations of the types of streamcourse are reflective of the hydrology of the area. Nearly 80 percent of the perennial stream mileage is in the Agua Fria National Monument and only 6 percent is in the Bradshaws (the remaining portion is on the Agua Fria River but outside the monument). Intermittent streams inventoried are divided more evenly with slightly more than half on the east side (monument) and the seasonal, or ephemeral riparian area streamcourses are predominantly on the Bradshaw side (90 percent). This is associated with the differences in geology and topography as they affect the hydrologic cycle, i.e., the granitoid and metamorphic or "basement" rock on the steep Bradshaws sheds excess precipitation rapidly and has limited ability to store water in aquifers for slow release to streamcourses. There is some temporary storage in alluvium and colluvium which drains out to streamcourses but the amount of storage and the generally steep gradients result in streamcourses ceasing to flow between wet seasons.

By contrast, the basalt and volcanic cover on the gentler terrain east side allows more water to percolate into fractures and voids in the rock, which in places may overlie layers of sedimentary formations (Wilson, 1988) providing greater storage capacity which discharges as base flows where stream channels intersect the aquifers.

A comparison of perennial streams between predevelopment condition maps (Freethey and Anderson, 1986) and Arizona Game & Fish Department maps (Valencia, et al, 1993) does not show significant areas of streamcourse which were perennial and have since been made ephemeral through diversion and/or groundwater pumping.

The Wilson (1988) study included measurements of base flow in late November and early June of water year 1981, times when losses to upstream diversions and riparian evapotranspiration would generally be at minimum and maximums, respectively. As he stated, the first group of measurements followed three years of heavy winter precipitation and opportunities of local groundwater recharge (in fact the wettest three consecutive winters on record at a number of precipitation stations). However the winter between the two base flow measurements was much dryer than average and the June measurements were considerably lower and the length of flowing streams was reduced.

One of the sites measured by Wilson in June 1981 appears to be very close to the Agua Fria River near Humboldt gage established in January 2000 at the outlet of the Prescott AMA. Wilson reports a flow of 0.80 cfs for June 2, 1981. The current Humboldt gage recorded flows of 0.66 cfs for June 2, 2000 and 0.78 cfs for June 2, 2001. It reached lows of 0.53 cfs on August 1, 2000 and 0.20 cfs on July 24, 2001. Lower base flows in late July and early August than in early June are consistent with records at the Mayer gage.

Wilson's water budget analysis estimated approximately 1,000 acre-feet per year of base flow in the Agua Fria River at Humboldt for water year 1981. A brief evaluation of base flow measurements since that time suggest that the average annual base flow has been in that general range. Base flow has varied by season and year, usually highest during the winter months when there is less groundwater pumping for irrigation in the lower portion of the AMA. It usually declines through the growing season, then recovers in the fall. Effects of the current drought are not readily in base flow measurements through the spring of 2002.

Wilson also took base flow measurements at several other points on the Agua Fria plus on Ash Creek, Little Ash Creek, Sycamore and Little Sycamore Creeks, and Big Bug Creek.

BLM hydrologists took streamflow measurements on a number of streams between 1992 and 1998, with many being during periods of base flow. Besides different segments of the Agua Fria, they included Ash Creek, Little Ash Creek, Dry Creek, Sycamore Creek, Big Bug Creek, Indian Creek, Silver Creek, Larry Creek and a tributary, Lousy Canyon, Dripping Spring, Slate Creek, Antelope Creek and Black Canyon Creek.

Both low flow and peak flow probabilities for stream gage stations are presented in the USGS Statistical Summaries through Water Year 1996 (Pope, et al. 1998). Low flow data for the Mayer gage is skewed by the presence of the Perry canal which diverted much of the low flow for many years until it was washed out in 1977. However, even in recent years since the canal has not been usable, summer flows have commonly been reported at less than 1 cfs and as low as approximately 0.2 cfs. Based on a 1941-96 data record it had a 50 percent probability of a 7 day low flow of 0.27 cfs.

The Rock Springs gage statistical summary shows a 50 percent probability 7 day low flow of 0.68 cfs.

3. Peak Flows. Peak flow probabilities are displayed in the statistical summaries based on the period of record for the specific gaging station. The Arizona Department of Transportation Highway Drainage Design Manual, Hydrology uses the Mayer gage as an example for development of flood frequency analysis. It is based on peak flow records for 1940 through 1989 (and was prior to the flood of January, 1993, the second highest on record). It compares closely with the USGS statistical summaries, based on 1940-1996. The ADOT study calculates a 5 year recurrence interval (20 percent probability) peak of 5,550 cfs while the USGS calculation is 5,920. For the 100 year recurrence interval (1 percent probability) the ADOT study calculates 37,000 cfs and the USGS 35,900. These differences are not significant.

During the 1980's the U.S. Army Corps of Engineers developed design flood flows for the Agua Fria during the planning and design for the New Waddell Dam which impounds Lake Pleasant. Their design floods ranged from 61,500 cfs for a 5 year recurrence interval to 135,000 cfs for a 100 year recurrence interval.

The following compares peak flow estimates for 5 and 100 year recurrence levels for the different size watersheds with differing periods of record for use. Peak flow estimates for the Agua Fria at Mayer & Rock Springs gages and at Waddell Dam plus the Turkey Creek gage are included. In addition, it displays similar statistics for the New River watershed which is adjacent to the watershed on the southeast boundary. Flows for 5 year and 100 years are displayed in both cubic feet per second (cfs) and cubic feet per second per square mile (csm). All are from the USGS statistical summaries except for those for the Agua Fria at New Waddell Dam which were developed by the U.S. Army Corps of Engineers. This value is commonly used for comparison of watershed and climatic characteristics. In general it is expected that the value for csm decreases somewhat with increasing watershed size.

Gage	WS Area Sq Mi	Period of Record	5 Year Recurrence Interval		100 Year Recurrence Interval	
			cfs	csm	cfs	csm
AF Mayer	585	1940-1996	5,920	10	35,900	61
AF Rock Springs	1,110	1920, 1970-1996	7,000	6	211,800	190
AF Waddell Dam	1459	*	61,500	42	135,000	92
Turkey Creek	89.4	1980-1982	1,700	19	9,810	110
New River	68.3	1961-82	3,150	46	37,500	550

*Calculations approved in 1988. Used combined methodologies and data from a number of sources, including Mayer gage.

There is obviously not a clear relationship between these calculated peak flows for 5 and 100 year recurrence intervals and watershed size. The Agua Fria watershed above the Mayer gage has a higher proportion of gentle terrain, has more areas of alluvial sedimentary surface geologic formations, and less exposure to tropical masses of moist air from the south than does the south end of the Bradshaws which drains to the Rock Springs gage and Waddell Dam site. The Waddell Dam site 100 year recurrence interval flow of 135,000 cfs is quite close to the estimated flow of 127,000 cfs in 1895 (Schuyler, 1903).

Floods have been a problem on a few occasions, including a tragic accident in December, 1978 when the Agua Fria River bridge on Interstate Highway 17 in Black Canyon City was washed away, taking a crossing automobile and driver with it. Floodplain maps under the guidelines of the Federal Emergency Management Agency have been developed for areas where improvements may be subject to damage, e.g., Black Canyon City, Mayer, Spring Valley. Yavapai County maintains the maps and has them digitized in their Geographic Information System (GIS).

4. Groundwater. Groundwater information for the entire watershed is displayed by Littin (1981). Groundwater in the northern portion of the watershed (north of about 34°15') is described and analyzed in more detail by Wilson (1988) based on conditions up to, and including, water year 1981. Halpenny (1970) evaluated groundwater in alluvium along lower Big Bug Creek and the effects its pumping would have on streamflow.

It is believed that much of the groundwater recharge is occurring in drainages passing through alluvium. In the large area with basalt surface geology in the east and northeast there may be some groundwater recharge through faults and fractures in the basalt. Geologic studies in the Beaver Creek watershed in the adjacent Verde watershed found water infiltrating into channels along fault lines within basalt and associated volcanics of the same general age (Scholtz, 1969; McCain, 1976).

The large land masses of granite and metamorphic rock (Wilson's "basement unit") are not believed to have as much groundwater recharge. Water may drain through the soil and adjacent weathered rock/subsoil downslope to drainages where it surfaces and drains down channels. This may take a period of weeks following periods when the soils are fully saturated.

Wilson displays the potentiometric surface (water table) in the northern part of the watershed along with the generalized direction of groundwater flow. In general, the flow is toward the Agua Fria River following the overall land surface pattern. He illustrates a narrow, localized aquifer along Big Bug Creek in the vicinity of Mayer which appears to be separated from the more general aquifer by a few miles. Littin displays general groundwater flow in the southern portion as being downslope toward the Agua Fria River.

The watershed is not characterized by a high density of springs. Several, e.g., Beehouse, Nelson Place, originate in the higher portion of the east side and initiate segments of perennial streams. Littin cites several around the southern base of the Bradshaws, including Castle Hot Springs reported to flow more than 200 gallons per minute (Ward, 1977).

Groundwater is the primary source for domestic use in the watershed. As discussed under land use, that demand is growing rapidly. In the northwest portion of the watershed generally north of Mayer a significant portion of the private and state trust land, as well as BLM land recently proposed for exchange to private ownership, is located on Wilson's "basement unit" of granitics and metamorphics. Its aquifer properties are rated as much less favorable for well development for public or commercial water supplies (Wilson, 1988, page 21). In the adjacent Prescott AMA it is identified on maps as "hardrock" where it is the surface formation. The current management plan (Arizona Department of Water Resources, 1999) says of this unit,

> "There are a large number of domestic wells which tap into fissures and cracks in the Basement Unit. However, the Basement Unit has very limited groundwater storage and production capacity, being a hardrock area, and because yields are small, is not regarded as an aquifer for other than domestic purposes."

Further east and southeast appears to be more favorable according to the data available for that report.

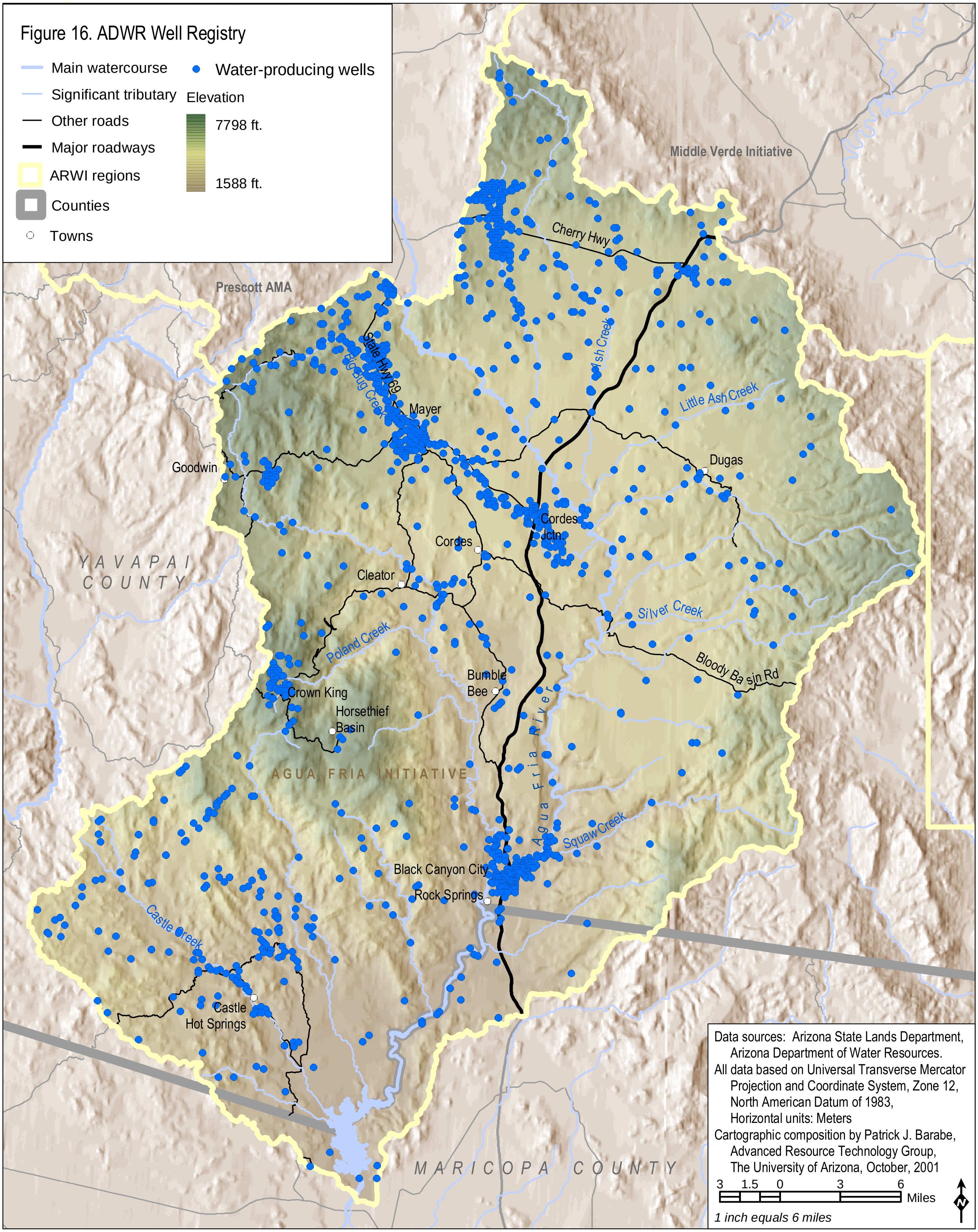


Figure 16. ADWR Well Registry
Main watercourse
Significant tributary
Other roads
Major roadways
ARWI regions
Counties
Towns
Water-producing wells
Elevation
7798 ft.
1588 ft.
Middle Verde Initiative
Prescott AMA
Cherry Hwy
State Hwy 69
Big Bug Creek
Ash Creek
Little Ash Creek
Mayer
Goodwin
Dugas
Cordes Jctn
Cordes
Cleator
YAVAPAI COUNTY
Silver Creek
Poland Creek
Bloody Basin Rd
Bumble Bee
Crown King
Horsethief Basin
AGUA FRIA INITIATIVE
Agua Fria River
Squaw Creek
Black Canyon City
Rock Springs
Castle Creek
Castle Hot Springs
MARICOPA COUNTY
Data sources: Arizona State Lands Department, Arizona Department of Water Resources.
All data based on Universal Transverse Mercator Projection and Coordinate System, Zone 12, North American Datum of 1983, Horizontal units: Meters
Cartographic composition by Patrick J. Barabe, Advanced Resource Technology Group, The University of Arizona, October, 2001
3 1.5 0 3 6
Miles
1 inch equals 6 miles
N

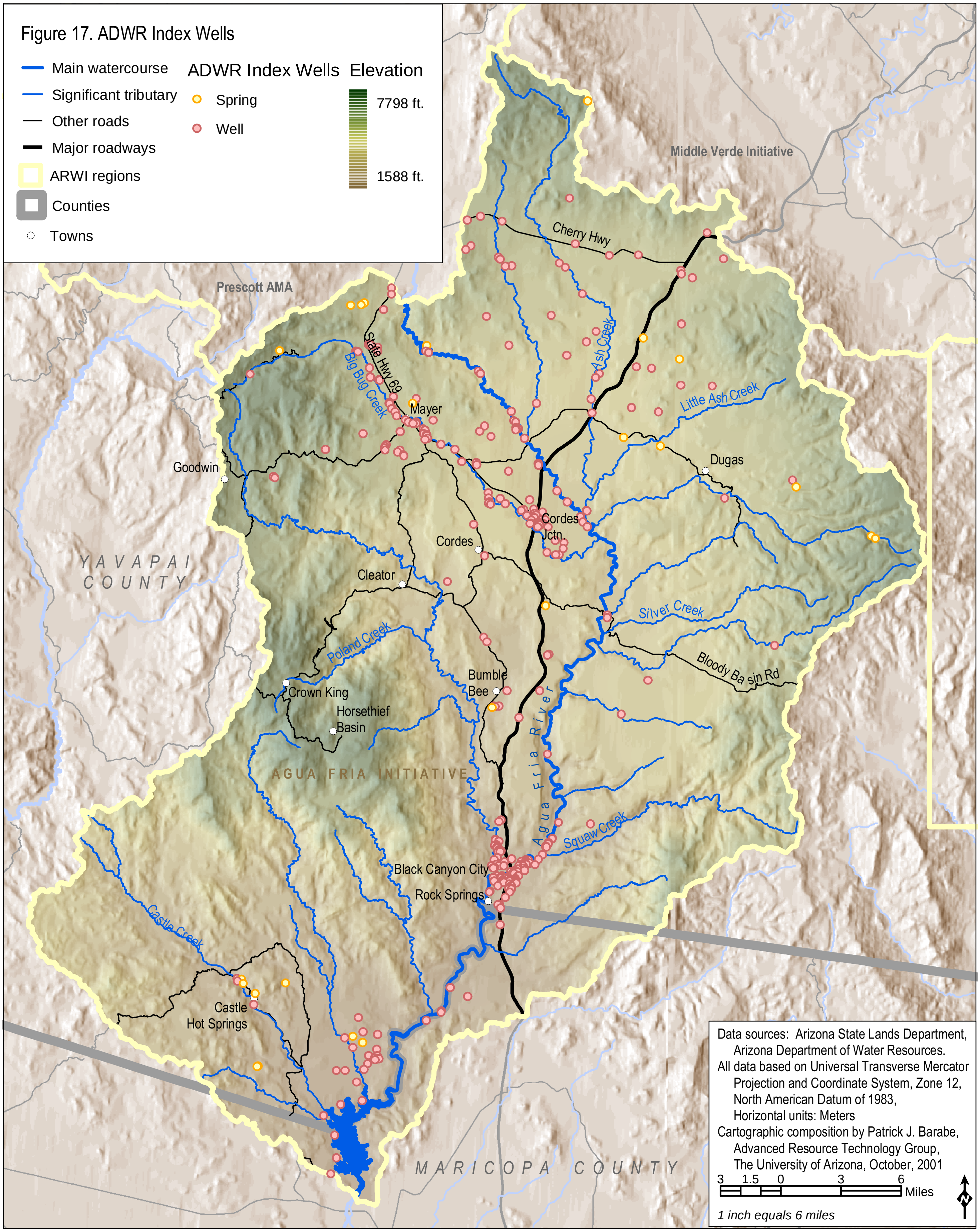


Figure 17. ADWR Index Wells

Figure 16 displays wells in the ADWR data base for the watershed. The index well map (Figure 17) shows the location of wells being used to evaluate water level conditions and potential changes. A total of 339 wells were identified in that category.

5. Watershed Condition. The condition of the watershed has been mentioned by stakeholders as important. This includes both the streams and riparian areas as well as the uplands. There has been a considerable amount of inventory and assessment of the riparian vegetation and associated streamcourses. The BLM conducted riparian surveys during the late 1980's and early 1990's, beginning with the National Wetlands Inventory maps and aerial photo analysis with a threshold minimum of at least ¼ mile of riparian area. Some areas were surveyed two or more times so that comparisons could be made. Beginning about 1995 riparian areas were evaluated with the Proper Function and Condition procedure. This procedure is used to assess the physical functioning of riparian areas considering hydrology, vegetation, and soil and landform attributes. Its classification system helps develop priorities for more detailed analysis where there appear to be problems or where it is indicated that uses and/or management activities may be limiting function. There are three primary classifications: Proper Functioning Condition, Functional - At Risk, and Nonfunctional. For those assessed as Functional – At Risk the trend is assessed as being upward, downward, or not apparent.

Figure 18 illustrates the classification by type of streamcourse for the BLM lands, using the most recent evaluations – generally 1997-2000. The perennial streams are rated in the best condition with more than half rated as proper functioning condition, and more than half of the functional – at risk rated as having an upward trend. The ratings get progressively less healthy as the methodology is applied to intermittent streamcourses and then seasonal streamcourses. Nearly 30 percent of the seasonal streamcourse mileage is rated as functional – at risk with a downward trend. This is similar to the distribution of streamcourse types between the east side and the Bradshaws. Only one streamcourse on the east side, the 1.76 mile Badger Springs Wash, is classified as functional – at risk with a downward trend.

The Prescott National Forest conducted a riparian inventory with sample segments in late spring and summer 1995; however, the data base does not contain mileages. Nine streams on the east side and four on the west and northwest (Bradshaws and Mingus) were evaluated. Rather than PFC, a five class condition rating from very poor to very good was used. On the east side one rated very good, one good, four rated fair, one poor and two very poor. In the Bradshaws two rated poor and one fair, while one on the south end of Mingus Mountain rated good. The timing of these surveys was after heavy scouring floods in 1993 & 1995, with those in 1993 being some of the highest peak flows on record. In the adjacent Verde River basin many areas scoured to bars of sand and cobbles in the spring of 1995 had revegetated with dense riparian vegetation by 1999.

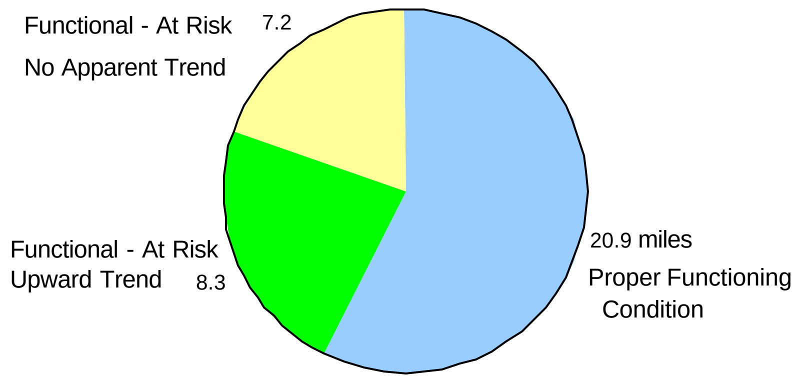
There is not a commonly agreed upon protocol for evaluating upland watershed conditions. The Prescott National Forest has used a detailed process for evaluating watershed condition within the middle Verde watershed (Prescott National Forest, 2001) and in the spring of 2002 are working on an evaluation for their portion of the Agua Fria

Fig.18. PROPER FUNCTION AND CONDITION RATIONGS
BLM RIPARIAN AREAS

Miles by Classification

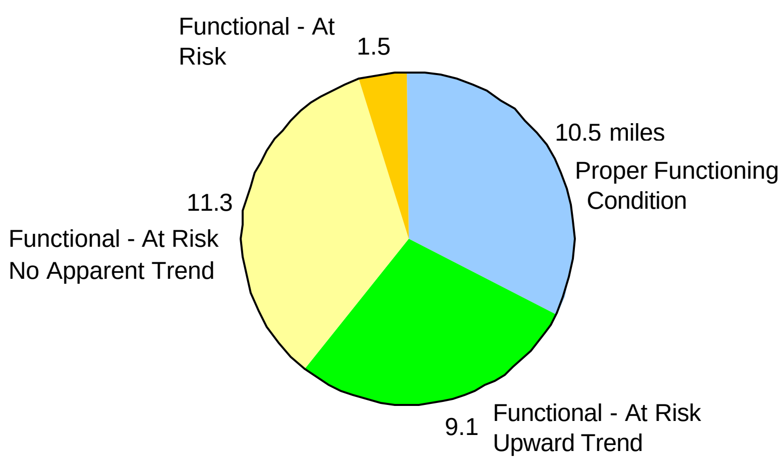
Perennial Streamcourses

36.4 miles



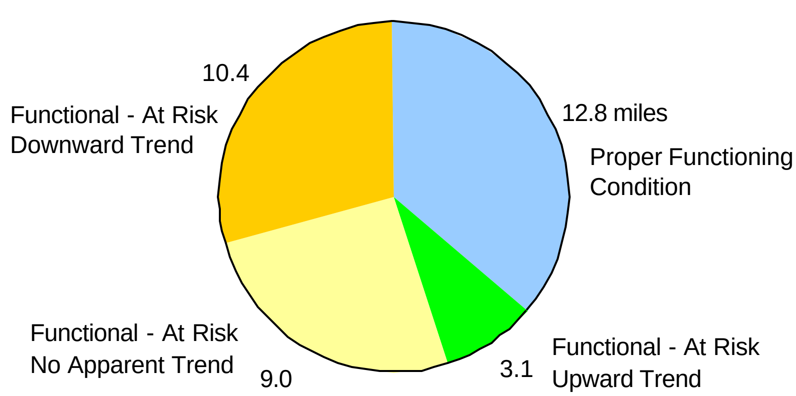
Intermittent Streamcourses

32.4 miles



Seasonal Streamcourses

35.3 miles



watershed. Their system is heavily dependent on ratings of soil condition, based on their Terrestrial Ecosystem Survey (TES). It considers factors of soil erosion, hydrologic function, and nutrient cycling using a tabular set of descriptors to classify soil condition as "satisfactory", "impaired", or "unsatisfactory". In addition to the quantitative and qualitative information collected in preparing the TES, additional field examination and data collection is done. Other factors used in evaluating watershed condition include riparian and streamcourse health and water quality. In the Verde watershed they reached conclusions of Verde River water quality and riparian condition being satisfactory but significant portions of the upland watershed being less satisfactory (moderate to low integrity relative to potential). This is not fully consistent with many widespread beliefs that the stream reflects the watershed.

The BLM in the spring of 2002 is in the process of evaluating ecological conditions, using the soils inventory as a starting point for field review. The results of this inventory and analysis will be incorporated into the planning for the Agua Fria National Monument.

Condition of rangelands is sometimes used as a surrogate for watershed condition. There are many similarities, especially for rangeland evaluation systems based on ecological succession status. However, there are some differences as most watershed evaluation procedures rely heavily on protection of the surface soil through the density of protective plant and litter cover. The types of plant communities that provide the densest ground cover are not always the highest successional stages or most desirable from a sustained forage production standpoint.

The watershed and its vegetation have evolved with the climate, including its cycles of drought and flood. Disturbances from fire, insects and plant diseases and parasites have affected the vegetative cover that covers the watershed. Human activities have been superposed on the natural system, often without full understanding of the natural system's dynamics. European effects started with mining in the 1860's which most affected stream channels through physical disruption of hydraulic mining, e.g., sluicing and associated placer mining activities (the cover of the 1988 Wilson report is a photo of such activity in Lynx Creek , a tributary to the Agua Fria in the Prescott AMA portion of the Agua Fria watershed).

Riparian vegetation and streamcourses are more resilient than other vegetation types and recover from disturbances – whether natural or human induced – more rapidly due to the constant or nearly constant availability of water for growth. However, repeated impacts can prevent recovery. For example, impacts from both livestock grazing and indiscriminate ATV use in portions of the Agua Fria River within the Agua Fria National Monument were observed to be constraining reestablishment of riparian vegetation. The semidesert grassland, woodland, and Sonoran desert scrub are much slower to recover from impacts that alter soil productivity or change basic plant composition.

One factor that periodically changes watershed condition, at least temporarily, is large scale fire, especially in the chaparral vegetation type. Large fires of 10,000 acres or more occur. Major fires of the last fifty years include the 18,000 acre Mingus Mountain fire of

1956, the 28,000 acre Battle Fire of 1972 and the 28,000 acre Castle Fire of 1979. Following fires in the chaparral, erosion and downstream deposition occur for the first two to three seasons before sprouting and germination of shrubs again provide soil protection. There are some other effects such as generally enhanced downstream riparian condition due to influx of water, nutrients and sediment to deepen the material for root development. Burning of very large contiguous areas in the same drainage may lead to downstream flood flows that scour out riparian vegetation and the alluvium supporting it, leaving bedrock channels in the upper portion of streamcourses. Reducing the continuity of large fuel masses so that smaller contiguous areas are burned at one time may allow the benefits to nearby riparian areas without the long term damage.

6. Water Quality. The general situation regarding water quality has been summarized by Enterline (2001). The Arizona Department of Environmental Quality (ADEQ) in their 1998 Unified Watershed Assessment for the state classified the watershed (including the AMA portion and the segment downstream from Lake Pleasant to the confluence with the Gila River) as Category I, the highest priority category for funding watershed restoration activities.

The 1998 Water Quality Assessment by ADEQ included assessments for six separate reaches of the Agua Fria River, comprising 45 miles, plus segments of 16 other streams totaling 246 miles. Of this number, one segment of the Agua Fria River was assessed as water quality limited due to turbidity. Turkey Creek and Galena Gulch were also assessed as water quality limited due to heavy metals associated with past mining activities.

Water quality data has been obtained by the USGS at their stream gage sites as well as by special studies, e.g., Scott (1994), Wilson (1988). USGS data is available through their website for water data. The number of water quality samples obtained at USGS sites ranges from 3 at Boulder, Humbug, and Cottonwood Creeks to 72 at Turkey Creek and 214 at Rock Springs. A wide variety of chemical constituents (including nutrients, metals, organics and inorganics), as well as some physical and biological parameters (and occasionally radiological) are reported.

Arsenic is a naturally occurring element common in groundwater in the southwest, often in concentrations exceeding the federal drinking water standards implemented in 2001 (10 micrograms per liter, or about 10 parts per billion, reduced from the previous standard of 50). Water in wells and surface water near mine tailings piles was found to have a variety of metals. In addition to arsenic, very high concentrations were found for zinc, cadmium, molybdenum, mercury, lead, nickel, and copper (Scott, 1994), with most exceeding drinking water standards. Some surface water samples during monsoon storm flows have been found to have very high concentrations of iron. Fine sediments can provide a transport mechanism for heavy metals. Land disturbances in the general area of sources of heavy metals, e.g., around tailings piles, could increase the likelihood of offsite movement through increased runoff from storms and sediment moving offsite along with potential pollutants.

Littin (1981) cited the effect of aquifer geology on water quality. In the Black Canyon City area wells into the underlying schist had very high levels of arsenic and high levels of fluoride. However, those drawing from the overlying sand, gravel, and silt had fluoride levels an order of magnitude lower. High fluoride levels were also found in groundwater from Castle Hot Springs and south toward Lake Pleasant.

7. Water Uses and Rights. The majority of surface water use is downstream in the Maricopa Water District (aka Maricopa Municipal Water Conservation District No. 1) below Lake Pleasant. Its predecessor was the Agua Fria Water and Land Company which filed for rights to appropriate water from the Agua Fria in 1888. According to a report prepared for the company by a consulting hydraulic engineer (Schuyler, 1903), a masonry diversion dam was partially completed in 1895. Schuyler's report also stated that numerous streamflow measurements had been taken from 1889 to 1895 by the company's chief engineer, Capt. W.A. Hancock and flows summarized on an annual basis. This reported runoff for the seven year period averaged about 250 thousand acre-feet per year. Recognizing that 1899 to 1895 appeared to have been a particularly wet sequence, and that succeeding years had significantly less flow on the Verde and Salt Rivers, Schuyler adjusted his estimates downward. In his report he gave the opinion that,

> "…in the majority of years, say 8 out of 10, a supply of 140,000 acre-feet can be depended upon, and that, although in occasional years of drouth the minimum flow may be reduced to about 80,000 acre-feet, the enterprise can safely be based on the use of about 140,000 acre-feet gross on the average.."

Schuyler's estimates based on information provided to him for this very short period of time have not been borne out. As discussed under water yield, the mean annual water yield from 1912 through 2000 was 82 thousand acre-feet and the median was about 40 thousand. Schuyler recommended construction of a dam and canal system and provided preliminary engineering information and cost estimates. However, the Waddell Dam was not completed until 1927. It had a storage capacity of 158,000 acre feet.

The New Waddell Dam, part of the Central Arizona Project (CAP) was completed in 1994, inundating the old dam and increasing Lake Pleasant's storage capacity to 1.3 million acre feet, with the additional capacity allocated to CAP.

Surface water is diverted upstream within the watershed in limited amounts from both the Agua Fria River and Ash Creek. The water rights and claims registry of ADWR lists 2,229 filings. A breakdown of types of filings includes:

Filing Type		Number
3R,4A, & 33	Filings under state water code (since 1912)	407
36	Filings under water rights registration (use predates 1912 water code)	1,465
38	Filings under Stockpond Registration Act	357

Surface water rights are a part of the Gila River adjudication. The Agua Fria upstream from Lake Pleasant has been designated as a specific watershed within the adjudication.

Wells registered with the Department of Water Resources are included in their "Wells 55" database. Analysis of this database found approximately 2100 wells; however, only about 1740 were listed as being in use for water production, the remainder were for monitoring or testing, geotechnical exploration, abandoned, or had not listed use. Of those with a listed use the following is the breakdown by type of primary use.

Primary Use	Number	Percent
Domestic	1165	67.0
Livestock Watering	308	17.7
Irrigation	159	9.1
Mining & Exploration	61	3.5
Muncipal & Water Co.	33	1.9
Industrial & Commercial	14	0.8

The domestic wells are predominantly for single family residences. The livestock watering wells were distributed by owner as follows:

BLM	85
Prescott National Forest	90
Private	81
Arizona State Trust Lands	42
Tonto National Forest	10

The municipal and water company wells were primarily at Mayer, Black Canyon City, and Cordes Lakes.

II. WATERSHED ISSUES

At a stakeholders meeting held October 16, 2000 issues were identified and prioritized. Grouping produced four primary areas – developing a water budget, watershed health, water quality, and water rights.

A. Water Budget.

One of the highest priority issues identified at the stakeholder workshop was developing a water budget for the area, especially the upper portion. In particular, there was a desire to determine how much water is available and how much is being used.

1. Background. Yavapai County is one of the most rapidly growing areas in Arizona. The adjacent Prescott Active Management Area (AMA) was declared in a state of groundwater mining in early 1999, meaning that new major water users have to obtain water sources other than new use of groundwater. This is expected to divert new major developments to adjacent areas not governed by AMA rules. The area's mild climate, existence of transportation and utility corridors, and proximity to the rapidly growing Phoenix metropolitan area all contribute to the expected growth. There are existing private lands as well as Arizona State Trust lands which could be developed following sale or long term lease. There are concerns that new major uses of groundwater might impact existing water users. There are also needs to know where the water resources can best be developed to accommodate increased growth with minimal impact to existing uses, including instream flows.

1. Planning Questions:

- How much water is being recharged to the aquifer and in what locations?
- How much water is being withdrawn from the aquifer and in what locations?
- Is groundwater storage in the aquifer increasing, decreasing, or remaining about the same?
- How much water is coming into the area as streamflow from the Prescott AMA? Is this amount changing?
- How much streamflow is generated within the area and what is its disposition, i.e., how much is diverted for consumptive uses, how much contributes to groundwater recharge, how much reaches Lake Pleasant, etc.?
- What is the variation of streamflow? Is there a change over the time for which data is available?

2. Components of the Water Budget

- Precipitation – annual and seasonal
- Surface water inflow (from Prescott AMA)

- Groundwater inflow (if present)
- Storm (and snowmelt) runoff
- Evapotranspiration
- Groundwater recharge
- Water withdrawals
  - Groundwater
  - Surface water
- Discharge via stream baseflow and groundwater outflow

B. Watershed Health.

One of the higher priority issues identified at the stakeholder workshop was that of maintaining and improving watershed health. This included both the upland areas of the watershed and the riparian or stream course areas. This issue has some relationships with the first priority issue of developing a water budget and is also related to the issue of water quality. One component of this is the continued production of water from the watershed through groundwater recharge and maintenance of base flows.

1. Background. The condition of the upland watersheds is integral to the hydrologic function – i.e., when precipitation falls on the land its disposition is affected by the soil and vegetation, which in turn are affected by land uses, both historical and current. The amount of the precipitation which immediately runs off the land surface, and that which infiltrates into the soil to either be used for plant growth or to move toward recharging groundwater is dependent on this critical interface.

The desert and semi-desert ecosystems have developed in a climatic regime of wide fluctuations of precipitation, ranging from drought to flood. Human uses superimposed on that climatic regime can tend to exacerbate or ameliorate their effects on soils and vegetation. In the mid to late 1800's hard-rock mining using both shafts and placer activities rearranged large amounts of material in and adjacent to watercourses, with much of this since being redistributed by periodic floods. Like the rest of Yavapai County, settlers in the 1800's brought in livestock and herds eventually exceeded the capacity of the range, especially during the drought periods near the turn of the century.

There have been changes in vegetation which affect watershed condition. Large areas have seen increases in pinyon-juniper and reduced grasses and fibrous rooted plants. A number of introduced plants have also increased at the expense of native species. This has been the case on both some of the uplands and in riparian areas. Examples include annuals such as cheatgrass (*Bromus tectorum*) and foxtail (*Bromus rubens*) on uplands and salt cedar (*Tamarix pentandra*) in riparian areas.

With rapidly increasing development of private lands and accelerated recreational use of public lands and state trust lands, their impacts to vegetation and the soil surface may affect hydrologic function. An increasing concern is the dumping and littering of waste materials, including some which are toxic, on public, state trust, and unfenced private lands. This is particularly the case along major transportation arteries such as I-17 and Highway 69 and on public and state trust lands surrounding communities.

Large areas of the watershed are in chaparral vegetation with lesser portions in ponderosa pine. These were subject to frequent fires prior to European settlement. Many decades of fire suppression have resulted in the buildup of fuel loads which, when ignited, burn with flame height and heat release sufficient to kill ponderosa pine overstory and create a situation vulnerable to heavy storm runoff and erosion during the first one to two monsoon seasons following the fire.

Riparian areas are quite limited in area but highly important to both humans and wildlife. Maintenance of base flow of stream segments and springs is necessary for the health of these critical areas.

2. Planning Questions:

- What is the general condition of the watershed uplands and the major components – by geomorphic, geologic, soil & vegetation, and land use criteria – in relation to its hydrologic function?

- What are the conditions of the riparian areas and how are they functioning? Are there trends in habitat conditions that warrant further study or management actions?

- What is the probable general effect of existing and expected land uses on flood flows and sediment production?

- Are the watershed conditions and the existing and expected land uses likely to maintain the water production of the watershed in terms of groundwater recharge and base flow. In particular, what are the likely general effects of urbanization?

- What are the areas which are particularly vulnerable to watershed damage – both onsite and downstream – from potential wildfires?

C. Water Quality

The issue of water quality is one that is common throughout the southwest where water is very scarce and use is shared. There are concerns for water quality both in surface water bodies and groundwater. Enterline (2001) describes the TMDL's for water quality limited waters.

1. Background. With most of the residential development in the watershed having individual septic treatment systems there is concern about potential effects to groundwater. Residential development in the Prescott AMA upstream from this portion of the watershed is expanding very rapidly. The town of Prescott Valley releases treated wastewater effluent into the Agua Fria channel about eight miles upstream from the AMA outlet – at that point a dry channel in an alluvial area. Agricultural uses downstream from that point raise questions about potential for fertilizer and pesticide residues to reach water.

Mining activities of the past have left tailings piles from ore processing in a variety of manners, including addition of processing agents such as mercury and cyanide. The ores contained various amounts of materials such as arsenic, lead, and zinc (Scott, 1994). In addition, the highly mineralized nature of some portions of the Bradshaws are a source for natural minerals occurrence, e.g., arsenic.

Illegal dumping and littering are believed to be having some effect on water quality, especially where done within the floodplain of streams or in dry washes tributary to streams. A wide variety of littering and dumping has been observed and reported ranging from beverage containers and plastic bags to construction materials, vehicle parts, and petroleum products.

2. Planning Questions

- Are there net water quality impacts from the Prescott AMA, either through surface or ground water?
- Are the residential areas in the watershed which are on individual septic tanks having adverse effects on water quality?
- Are activities in and adjacent to former mines adversely affecting water quality?
- Are violations of turbidity standards the result of natural conditions or human impacts? Are there reasonable management actions that would mitigate them?

D. Water Rights

Stakeholders expressed both concern and uncertainty on the issue of water rights.

1. Background. Water rights for surface flow are held by both local area users and downstream users in the Maricopa Water District (aka Maricopa County Municipal Water Conservation District No. 1) receiving water from Lake Pleasant.

The area is a part of the Gila River adjudication of water rights which has been in progress for many years. The watershed has been designated as a specific watershed for the adjudication. However, hydrographic surveys have not been made by the Arizona Department of Water Resources, suggesting that it may not be one of the earlier watersheds to be adjudicated.

The recent Arizona Supreme Court decision regarding subflow raises questions as to the appropriability of water from some of the wells in the watershed. Areas which could be affected include at least Black Canyon City and Cordes Lakes. As directed by the court in the ongoing Gila River adjudication, ADWR's March 29, 2002 response included time estimates by watershed to accomplish the necessary analysis and inventory for the watershed, including establishing the jurisdictional sub flow zone, evaluating and modeling cone of depression effects and identifying and documenting *de minimis* uses which are so small as to not be included in the adjudication. For the Agua Fria watershed the estimated time requirement was two to four months. However, it is expected that this process would not start until the watershed is designated by the trial court for litigation. In response to the court's direction, the Department made recommendations for *de minimis* domestic uses. The recommendations were that they be for a single residence serving household purposes and associated outdoor activities on adjoining land not exceeding 0.2 acres, with a quantity not to exceed 1.0 acre-foot per year.

Planning Questions

- Are surface flows of the Agua Fria overallocated?

- Do the exercise of downstream rights result in the necessity to reduce some existing upstream uses?

- Are existing wells affected by the subflow ruling and its implementation procedures? Where and to what degree?

III. RECOMMENDATIONS TO ADDRESS ISSUES

The next step is to move forward addressing issues on a priority basis with available resources. The following are recommendations to address issues.

A. Water Budget

1. Update the status of groundwater in the area of the 1988 Wilson report. Incorporate new information available since the information in that report. Identify major areas of recharge and make recommendations for protection to prevent actions that might adversely affect recharge. Make recommendations on additional studies, e.g, geophysical studies and highest priority additional monitoring wells. (Implementation of this recommendation has been started with a Rural Watershed Initiative funded project with the University of Arizona with Dr. Paul Ferre and graduate student Lizz Leon.)

2. Expand baseline information on hydrologic cycle components in east and northeast portion of watershed where data is lacking. This area generates a number of small streams tributary to the Agua Fria, including several within the National Monument. Information needs include additional precipitation gages, streamflow monitoring and groundwater level monitoring. There are opportunities to coordinate some with other

entities, e.g., precipitation gages with Yavapai County Flood Control (and possibly some peak flow streamflow monitoring). Collecting reliable data from a few well chosen locations is generally more usable than numerous locations with data of unknown reliability. There are some opportunities for use of citizen volunteers to participate, e.g., coordinated "sweeps" of streamcourses, using GPS technology to record locations of flow and nonflow within channels. This should be as a supplement to a coordinated effort of information acquisition and management. (The BLM is funding a project by the USGS to do some of this in the area of the National Monument because of the importance of maintaining springs and stream flows.)

3. Evaluate the need for detailed water budget and groundwater analysis in the Black Canyon City area, especially in light of the potential for subflow impacts of existing and potential wells.

4. Continue to monitor effects of Prescott AMA development to water quantity in the region, both as surface flow and, if found, groundwater movement.

B. <u>Watershed Health</u>

1. Reach agreement among agencies on basic data collection, analysis and classification procedures and protocol for evaluating condition of both riparian/aquatic communities and upland watershed conditions. For riparian areas this should be in addition to, and more quantitative than, the Proper Function and Condition (PFC) process. The PFC provides a basis for prioritizing where more quantitative information is needed. The procedures should be repeatable, defensible & documented, and capable of data storage and analysis. Participants should include both federal and state agencies including BLM, Forest Service, USGS Biological Survey, US Fish & Wildlife Service, Arizona Department of Environmental Quality, and Arizona Game & Fish Department, as well as Arizona universities and nongovernmental entities with expertise such as The Nature Conservancy. This recommendation is broader than just the Agua Fria watershed and is applicable statewide and possibly regionwide.

2. Evaluate, prioritize, and implement higher priority riparian protection and enhancement measures. Stream courses with base flow can most rapidly respond to protection. Physical protection from ATV and livestock use through fencing, vehicle barriers, education, and enforcement can often result in rapid riparian area recovery.

C. <u>Water Quality</u>

1. Monitor and evaluate effects of residential and commercial development on quality of both surface and ground water. Much of this can be done in cooperation with the Arizona Department of Environmental Quality. In particular, monitor water quality at entrance from the Prescott AMA. Participate with ADEQ in assuring monitoring and evaluation of commercial and industrial uses in areas with potential links to groundwater, e.g., underground mines, drainages where groundwater recharge is occurring.

2. Reduce and control water quality impacts from illegal dumping and littering. Through an aggressive campaign of education and enforcement, plus cleanup of existing dumping sites and littered streamcourses, develop an atmosphere that encourages stewardship of the watershed by both residents and visitors.

3. Continue to monitor identified sources of potential pollutants from past mining activities. The report by Scott (1994) is a basic reference, along with other water quality data. Evaluate need for on-site treatment to contain or remediate potential pollutants.

4. Work with ADEQ in evaluation of TMDL's and development of plans to address problems.

D. <u>Water Rights</u>

1. Evaluate the effect of the subflow issue on existing wells.

BIBLIOGRAPHY

Arizona Department of Environmental Quality. 1998. Arizona Unified Watershed Assessment for the Clean Water Action Plan, Oct. 1, 1998.

Arizona Department of Environmental Quality. 1998. Arizona Water Quality Assessment 1998. Volume I – Assessment Process and Analysis, 101 pp.
Volume II – Assessment Data and Standards, 159 pp.

Arizona Department of Transportation. 1993 (rev. 1994). Highway Drainage Design Manual Hydrology. Prepared by NBS/Lowry Engineers & Planners, Inc. and George V. Sabol Consulting Engineers, Inc. Res. Project No. HPR-PL-1-43(281).

Arizona Department of Water Resources. 1999. Third Management Plan, 2000-2010, Prescott Active Management Area, October 1999.

Baker, Malchus B., Leonard F. DeBano, and Peter F. Ffolliott. 1997. Hydrologic Regimes in Chaparral on the Battle Flat Demonstration Area. Proceedings of the 1997 Meetings of the Hydrology Section, Arizona-Nevada Academy of Science. April 19, 1987, University of Nevada, Las Vegas, Nevada.

Bureau of Land Management. 1993. Agua Fria, Arizona, Potential Wild and Scenic River Suitability Assessment. September, 1993. Phoenix District. Phoenix, Arizona.

Bureau of Reclamation. 1981. Inflow Design Flood Study New Waddell Damsite, Agua Fria River. Arizona. Arizona Projects Office. Phoenix, Arizona. April, 1981.

Dava and Associates. 2001. Yavapai County, Arizona General Plan, Phase 1, December 17, 2001. Yavapai County. Prescott, Arizona.

Dieterich, J.H. and A.R. Hibbert. 1988. Fire History in a Small Ponderosa Pine Stand Surrounded by Chaparral. In: Effects of fire management of southwestern natural resources: proceedings of the symposium, Nov. 15-17, 1988, Tucson, AZ. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station; 1990. General technical report RM : 191, pp. 168-173.

Enterline, Max. 2001. Watershed Restoration Action Strategy, Upper Agua Fria Watershed. Arizona Department of Environmental Quality.

Freethey, Geoffrey W. and T.W. Anderson. 1986. Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico. U.S. Geological Survey Hydrologic Investigations Atlas HA-664, scale 1:500,000, 3 sheets.

Halpenny, Leonard C. 1970. Effect of Cordes Lakes Development upon Streamflow in Agua Fria River. Water Development Company, Tucson, AZ. unpublished report.

Littin, G.R., 1981, Maps showing ground-water conditions in the Agua Fria area, Yavapai and Maricopa Counties, Arizona - 1979: U.S. Geological Survey Open-File Report 81-804.

McCain, Ronald G. 1976. Relationship Between Water Loss from Stream Channels and Gravity and Seismic Measurements: Beaver Creek Watershed 7, Coconino County, Arizona. M.S. Thesis, Northern Arizona University, Flagstaff, Arizona.

MacPhee, Douglas T. 2002. Range Conservationist, Prescott National Forest, Camp Verde, Arizona. Personal Communication.

Pope, G.L., P.D. Rigas and C.F. Smith. 1998. Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-Gaging Stations in Arizona through Water Year 1996. U.S. Geological Survey Water Resources Investigations Report 98-4225.

Prescott National Forest. 2001. Watershed Condition Assessment for Select Verde River 5th Code Watersheds, Prepared to address critical habitat for spikedace and loach minnow. Prescott National Forest, Prescott, Arizona.

Rosebrook, Jeb J. and Jeb S. Rosebrook. 1994. "The Old Black Canyon Highway", Arizona Highways, August, 1994, pp. 5-11, as quoted in Cordes Lakes/Spring Valley/Highway 69 Corridor Community Plan, page 2.

Scott, Paul S. 1994. Basic Geologic and Hydrologic Information, Bradshaw Mountains, Yavapai County, Arizona. Arizona Geological Survey Open-File Report 94-2, February, 1994.

Scholtz, Judith F. 1969. Investigation of Low-Stage Transmission Losses in Stream Channels on Watersheds 7, 9, 11, and 12, Beaver Creek Experimental Drainage Basin, Coconino County, Arizona. submitted to Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.

Schuyler, James D. 1903. Report on the Water Supply of the Agua Fria River, and the Storage Reservoir Project of The Agua Fria Water and Land Company for Irrigation in the Gila River Valley, Arizona. Hayden Arizona Historical Foundation, Arizona State University, Tempe, Arizona.

Sellers, W.D. and Hill, R.H., eds. 1974. Arizona Climate 1931-1972. University of Arizona Press, Tucson, Az. 616 pp.

U.S. Army Corps of Engineers. 1988. Hydrology for Evaluation of Flood Reduction By New Waddell Dam, Agua Fria River below New Waddell Dam to the New River Confluence. U.S. Army Engineer District, Los Angeles, California. Sept. 1988.

Ward, M.B. 1977. The Volcanic Geology of the Castle Hot Springs Area, Yavapai County, Arizona. M.S. Thesis, Arizona State University, Tempe, Arizona. 74 pp.

Wilson, Bruce M. 1990. Crown King and the Southern Bradshaws: A Complete History. Crown King Press. Mesa, Arizona.

Wilson, Richard P. 1988. Water Resources of the Northern Part of the Agua Fria Area Yavapai County, Arizona. Prepared by the U.S. Geological Survey. Arizona Department of Water Resources Bulletin 5.

Yavapai County. 1986. Black Canyon City Community Plan Update. Prepared by Yavapai County Planning staff with participation by Black Canyon City Advisory Committee.

Yavapai County Planning and Building Department. 1995. Cordes Lakes/Spring Valley/Highway 69 Corridor Community Plan. Yavapai County.

APPENDIX. INVENTORIES, DATA SOURCES & REFERENCES

Inventories, data sources, and references are discussed in two parts. First, is the statewide general system for land resources and then by subject area, e.g., geology, precipitation, etc. The list is not an exhaustive and totally complete listing of all sources of data or information. It includes the most relevant information sources found during the course of this analysis. It does not repeat citations from the bibliography, except where there was believed to be a need to further describe the availability of information.

The most comprehensive set of inventories relating to the watershed are contained in the Arizona Land Resource Information System (ALRIS), maintained by the Arizona State Land Department. A number of statewide inventories are maintained in a Geographic Information System (GIS) and are available for access via the internet. For this report the ALRIS database was used for landownership, geology, vegetation, soil hydrologic group, and riparian areas.

For each GIS coverage the ALRIS site provides metadata, or "data about data", giving available information regarding the inventory, its source, its scale of mapping, the date of mapping, and other relevant factors.

The ALRIS home page with a general description is available at:
http://www.land.state.az.us/alris/htmls/data2.html

The individual GIS coverages, including descriptions and metadata are available at:
http://www.land.state.az.us/alris/index.html

Landownership – Statewide landownership is one of the ALRIS GIS coverages, mapped at a scale of 1:100,000. For the majority of the watershed which is in Yavapai County, detailed information on landownership, including individual parcel ownerships, can be obtained via the internet at: http://www.co.yavapai.az.us/services/MappingIndex.asp.

Precipitation – Precipitation records and information is available from several sources. The National Weather Service Office in Phoenix contains current information and forecasts and can be reached at: http://www.phx.noaa.gov/

The Western Regional Climate Center has a database for Arizona with extensive precipitation and temperature data and statistics at:
http://www.wrcc.dri.edu/summary/climsmaz.html. This site contains both long term and 30 year (1961-90 and 1971-2000) averages for daily, monthly, and yearly precipitation, along with extremes.

The Arizona Weather site maintained by the University of Arizona in cooperation with the National Climatic Center at Asheville, NC contains some precipitation data not found in the previous listing. It is accessed at: http://ag2.calsnet.arizona.edu/cgi-bin/weather.cgi

For most comprehensive analysis of historical weather a combination of the two above sites is recommended.

Yavapai County Flood Control has a network of both recording and regular rain gages operated by volunteers which supplements the system of Cooperative Weather Stations managed and reported by the National Weather Service.

Maps of average annual precipitation for the period 1961-1990 by state are available from the National Resource Conservation Service at: http://www.ftw.nrcs.usda.gov/prism/prism.html.

Geology – The statewide geology map in ALRIS is at a scale of 1:1,000,000 and was used for the figure and map in this report. Other maps include:

Geologic Map of Yavapai County. 1958. Prepared by Arizona Bureau of Mines and University of Arizona. 1:375,000. Available from Arizona Geological Survey, Tucson.

Geologic Map of Maricopa County. 1957. Prepared by Arizona Bureau of Mines and University of Arizona. 1:375,000. Available from Arizona Geological Survey, Tucson.

Geologic Map of the Mount Union Quadrangle, Yavapai County, Arizona. 1972. C.A. Anderson and P.M. Blacet. US Geological Survey. 1:62,500.

Some references for geology include:
Scott, Paul S. 1994. Basic Geologic and Hydrologic Information, Bradshaw Mountains, Yavapai County, Arizona. Arizona Geological Survey Open File Report 94-2. Done for a preliminary environmental assessment of the impact of past mining activities on water quality. Covers area from Prescott-Humboldt south & southeast to Crown King and Black Canyon City. Summarizes numerous past geologic & mineral studies and discusses interpretations that can be made for water quality with available data. Contains a number of original maps compiling results of multiple studies. Map scale 1:100,000.

Reynolds, S.J. F.P. Florence, J.W. Welty, M.S. Roddy, D.A. Currier, A.V. Anderson, S.B. Keith. 1986. Compilation of Radiometric Age Determinations in Arizona. Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch, Bulletin 197. Statewide compilation of ages of rock formations determined by radiometric methods. Arranged both by age and geographic locale. Relevant geographic areas include Agua Fria area, Bradshaw Mtns., Hieroglyphic Mtns, New River area, and Lake Pleasant area.

St. Clair, Charles S. 1957. Geologic Reconnaissance of the Agua Fria River Area, Central Arizona. M.S. Thesis, University of Arizona. Broad scale description of geologic history and structure generally along the Agua Fria River corridor, with discussion of adjoining areas. Includes several black and white oblique photos from air to illustrate landforms and structure.

Evensen, James, M. 1969. Geology of the Central Portion of the Agua Fria Mining District, Yavapai County, Arizona. Ph.D. Dissertation, University of Arizona. Area is about three miles east and northeast of Mayer. Geologic formations and mineralogy emphasized. Agua Fria River cuts through basement rock in this area.

Soils – The statewide soils coverage in ALRIS is from the Natural Resources Conservation Service (NRCS) and is primarily at at a scale of 1:250,000. Other soils inventories include:

Soil Survey of Yavapai County, Arizona, Western Part. 1976. USDA Soil Conservation Service (no NRCS) and Forest Service in cooperation with Arizona Agricultural Experiment Station. Scale 1:31,680. Soil classification is to the series level. Productivity ratings and interpretations for use and management are given. Includes descriptions of representative soil profiles. Displayed on orthophoto map sheets. Includes portion of watershed within Yavapai County except for that within the Tonto National Forest and the east division of the Prescott National Forest. Available from the NRCS. Portions scheduled to be digitized for GIS in 2002 through BLM.

Terrestrial Ecosystems Survey (TES) of the Prescott National Forest. 2000. USDA Forest Service, Southwestern Region. Scale 1:24,000. Soil classification to family level. Productivity ratings and interpretations for use and management are given. Does not include descriptions of soil profiles. Digitized and printed overlaying USGS 7.5 minute topographic maps. Prescott National Forest, Prescott, Arizona.

Terrestrial Ecosystems Survey, Agua Fria Grasslands portion of Tonto National Forest. USDA Forest Service, Southwestern Region. Similar to TES for Prescott National Forest. Unpublished, to be included in survey for complete Tonto National Forest, in progress in 2002.

General Ecosystems Survey, Southwestern Region, U.S. Forest Service. 1989. Scale 1:250,000. Covers portion of Tonto National Forest not yet covered by 1:24,000 surveys. Available from Tonto National Forest, Phoenix, Arizona.

Vegetation – Vegetation maps covering the watershed are part of statewide maps displayed in ALRIS. The map selected for use in this report was digitized from a base map prepared by Brown and Lowe at a scale of 1:100,000. In the ALRIS index it is labeled "Natveg". Another commonly used vegetation map from ALRIS is GAP (labeled "Gapveg"). It has been developed from satellite imagery and is at a scale of 1:100,000. It has much greater resolution -- i.e., it classified vegetative communities in more detail – but was found to have errors within this watershed and there was less confidence in its use.

The TES surveys for the Prescott National Forest and the Agua Fria Grasslands portion of the Tonto National Forest contain detailed vegetation information, in addition to soil classification and mapping, at a scale of 1:24,000.

Riparian vegetation is included in an ALRIS coverage prepared by the Arizona Game & Fish Department, mapped at a scale of 1:100,000. Riparian inventories are available through the National Wetlands Inventory of the U.S. Fish and Wildlife Service with descriptions, metadata, availability, etc. accessed at http://www.nwi.fws.gov/. The inventories are displayed on 7.5 minute (1:24:000) USGS maps. More detailed riparian inventories have been conducted by the BLM and Forest Service.

Streamflow– Data for the USGS streamgages, both current and former, is available through the USGS Arizona Water website: http://az.water.usgs.gov/
The current active stream gages can be accessed via real time coverage as follows:

Go to real time stream flow at http://az.waterdata.usgs.gov/nwis/current/?type=flow then scroll down to Lower Gila River Basin. The Agua Fria stream gages near Humboldt, Mayer, and Rock Springs can then be accessed. Historic information can also be accessed for these gages through this website. Historic information on gages which have been closed can be accessed using the site number from Table 7, beginning with 095 and using all eight digits.

Statistical information on streamflow, including peak flows and low flows, through water year 1996 for USGS gages is available through Water Resources Investigations Report 98-4225 by Pope, et al, cited in the bibliography.

Water Quality – Data for water quality collected by the USGS at their stream gage sites is available through the water website, http://az.water.usgs.gov/ and is an option that can be selected.

Water Rights and Uses – The Arizona Department of Water Resources maintains records on water uses and rights. Data bases are available via CD-ROM for both surface water uses and wells.

Floodplain Areas – The Federal Emergency Management Agency (FEMA) is responsible for floodplain delineation. Floodplain maps have been prepared and are available covering all areas within the watershed. Map scale varies, depending on drainage patterns and presence of developed or potentially developable areas subject to flood damage. Index of coverage on file at Yavapai County Flood Control office, Prescott.

Population– Information from the census, with population and other demographics by census designated places is available at http://www.census.gov/census2000/states/az.html then "State by Place".

Population projections within Arizona are made by the Department of Economic Security and. Projections made in 1997 for specific communities, including Black Canyon City and Mayer within the watershed are at:
http://www.de.state.az.us/links/economic/webpage/popweb/subco97.html

Other - Other general information of interest includes:

A number of historical photos and records are in the archives of the Sharlot Hall Museum in Prescott. Information and a catalog of many of the archived materials is available at: http://www.sharlot.org/archives/ . There are links to other sources of historical information, e.g., the Hayden Arizona Historical collections at Arizona State University.